STATE OF MONTANA
WATER RESOURCES BOARD

TONGUE RIVER PROJECT

BASIC DESIGN REPORT

BECHTEL

BECHTEL CORPORATION
SAN FRANCISCO

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I SUMMARY

This report presents the basis for the design of the Tongue River Project which is to develop industrial water supplies in southeastern Montana.

Since the late 1800's, water from the Tongue River has been used for irrigation and domestic purposes. Municipal uses have also been more recently developed. In Montana irrigation has been by direct diversion from the main Tongue River with water rights dating from 1886. In 1939, the Montana State Water Conservation Board constructed the Tongue River Dam to impound the Tongue River Irrigation Reservoir, the major storage reservoir in the basin, for irrigation and other beneficial uses.

In the high plains country of northeastern Wyoming and southeastern Montana, extensive deposits of coal are available for development. Technological advances in the use of coal-fired steam power plants and development of economical methods of converting coal to petroleum products are presently making exploitation of these vast coal deposits economically feasible. Such developments require substantial quantities of water for cooling and process consumption. Therefore, it is anticipated that further uses of water, particularly in the Tongue River Basin, will be largely for industrial purposes.

The Montana legislature in 1967 authorized the Montana Water Resources Board to carry out investigations and engineering for the Tongue River Project to develop industrial water supplies for use in southeastern Montana.

As a first step in the engineering studies, the determination of the relationship between water supply, firm yield and reservoir sizing was undertaken.

Historical flow records for the Tongue River near the state line are available since 1929, providing an adequate basis for water yield studies. However, the Tongue River, a major tributary of the Yellowstone River, flows from Wyoming into Montana and both of these states share in rights to use its waters.

To provide a basis for usage of waters of the major rivers which flow from Wyoming into Montana, these two states concluded the Yellowstone River Compact in 1950. Before yield studies could be made, it was necessary to determine Montana's share of the unused and unappropriated water in the Tongue River.

A Water Allocation Study was made presenting two "allocations". The first, adhering strictly to the compact provisions particularly with respect to reservations of supplemental water, leads to conclusions which are believed unrealistic. The second "realistic allocation" was made based on analysis and judgement of realistic future conditions in the Tongue River Basin. Under the realistic allocation it was determined that a maximum firm yield of 112,000 acre feet annually could be developed by providing 450,000 acre feet of gross storage. Such storage, however, using the furthest downstream feasible damsite would require storing water across the border into Wyoming.

Therefore, a "Stage I" High Tongue River Dam has been planned using a storage elevation 3438, some three and one-half feet below the state line streambed elevation. This Stage I reservoir has 320,000 acre feet of gross storage and a firm yield of 100,000 acre feet annually. Part of the firm yield is allocated to agricultural uses under agreements for the existing Tongue River Irrigation Reservoir. The dam is designed for future raising to provide 450,000 acre feet of storage.

In addition to the firm yield, discharges of 342 cubic feet per second are provided to satisfy adjudicated and Indian water rights and 75 cubic feet per second of winter releases.

A study was made to determine the probable time required for first filling of the reservoir. It appears that a filling period of four to six years should be provided.

The Stage I dam is about 200 feet high, 3200 feet long and contains over 10,000,000 cubic yards of earth materials. The spillway has been designed to pass probable maximum flood which has a peak inflow of 183,000 cubic feet per second. The outlet works has been designed to pass 3000 cubic feet per second at maximum storage elevation.

The total specific construction cost, based on fourth quarter 1968 price levels is $22,133,000. Allowances for contingencies, engineering, construction management and escalation during construction bring the project cost to $32,229,000. Additional costs to be determined by the Montana Water Resources Board include cost of land and rights of way, escalation to start of construction, owner costs and financing costs of interest during construction and interest during first reservoir filling.

II. INTRODUCTION

PURPOSE AND SCOPE

This report presents the basis for the design of the Tongue River Project. This Project for the Montana Water Resources Board will develop additional industrial water supplies from the Tongue River in southeastern Montana in addition to the irrigation supplies already developed. The Location and Vicinity Maps of the Tongue River Project are shown on Drawing 6694-11-001.

Summaries of hydrologic, geologic, and material exploration investigations are included. The history of water development in the Tongue River Basin is presented along with a description of the evolution of the Tongue River Project. The criteria and bases for design of the project features are summarized and discussed.

DESCRIPTION OF THE TONGUE RIVER SYSTEM

The Tongue River rises in the Big Horn Mountains of northern Wyoming and flows north and eastward through Wyoming into Montana, finally joining the Yellowstone River at Miles City in eastern Montana. The Tongue River Basin is approximately 150 miles long and 40 miles wide, and includes some 5420 square miles of drainage area.

The major water-producing area of the Tongue River drainage lies in the Big Horn Mountains in the basins of the tributaries North Tongue River, South Tongue River, Little Tongue River, Wolf Creek, Goose Creek, and Little Goose Creek. These tributaries flow north and east from the mountains and out onto the high plains, joining together to form the main Tongue River north of Sheridan, Wyoming. A number of ephemeral streams join the main Tongue River from the north. Prairie Dog Creek rises in the plains south and east of Sheridan and joins the main Tongue River just before it crosses the border into Montana.

In Montana, many small ephemeral tributaries flow into the northward-flowing Tongue River from the west. On the east, however, drainage is dominated by three major tributaries: Hanging Woman Creek, which joins the main river at Birney; Otter Creek, which joins at Ashland; and Pumpkin Creek, which flows into the Tongue River about 22 river miles above the confluence of the Tongue and Yellowstone Rivers at Miles City. A map showing the Tongue River Drainage Basin is presented on Drawing 6694-11-002.

HISTORY OF WATER USE IN THE TONGUE RIVER SYSTEM

Since the late 1800's, water from the Tongue River has been used for irrigation and domestic purposes. Municipal uses have also been more recently developed but the predominant use has been for irrigation.

In Wyoming, earliest water rights for irrigation date from before 1880. Extensive development of irrigation canal systems has taken place in Wyoming leading to exchange of water between tributary basins. Several reservoirs for storage of irrigation water as well as numerous stock ponds have been constructed. Importation of water from Piney Creek, a tributary of the Powder River, into the Tongue River Basin has been accomplished through the construction of irrigation canals.

In Montana, the predominant use of water has been for irrigation by direct diversion from the main Tongue River with irrigation water rights dating from 1886. In 1939, the Montana State Water Conservation Board constructed the Tongue River Dam to impound the Tongue River Irrigation Reservoir, the major storage reservoir in the basin,for irrigation and other beneficial uses. On the tributaries, wild flooding for irrigation has been widely practiced.

In the high plains country of northeastern Wyoming and southeastern Montana, extensive deposits of coal are available for development at shallow depth. Technological advances in the use of coal-fired steam-electric power generating plants and development of economical methods of converting coal to petroleum products are presently making exploitation of these vast coal deposits economically feasible. However, such developments require substantial quantities of water for cooling and process consumption. Therefore, it is anticipated that further uses of water in these areas and particularly in the Tongue River Basin will be largely for industrial purposes.

HISTORY OF THE TONGUE RIVER PROJECT

The Montana legislature in 1967 authorized the Montana Water Resources Board to carry out investigations and engineering for the Tongue River Project to develop industrial water supplies for use in southeastern Montana. On May 25, 1967, a contract was executed between the Montana Water Resources Board and Bechtel Corporation to carry out the investigations and engineering. At that time it was anticipated that the storage required for the project would be about 150,000 acre feet to be accomplished by raising the existing Tongue River Dam, and/or building a new dam downstream.

As a first step in the engineering studies, the determination of the relationship between firm water supply yield and reservoir sizing was undertaken.

Historical flow records for the Tongue River near the state line are available since 1929, providing an adequate basis for water yield studies. However, the Tongue River, a major tributary of the Yellowstone River, flows from Wyoming into Montana and both of these states share in rights to use its waters.

In order to provide a basis for usage of waters of the major rivers which flow from Wyoming into Montana, these two states concluded the Yellowstone River Compact in 1950. Before yield studies could be made, it was necessary to determine Montana's share of the unused and unappropriated water in the Tongue River.

On June 8, 1967, the Montana Water Resources Board authorized Bechtel Corporation to proceed with a study for determination of the unused and unappropriated water in the Tongue River for allocation under the Yellowstone River Compact. That study included:

1. Collection and evaluation of basic streamflow data.

2. Collection and evaluation of water rights data in both Montana and Wyoming.

3. Field investigation of water use and administration.

4. Determination of supplemental water requirements, and

5. Analysis of data and determination of unused and unappropriated water.

After intensive study, analysis, review by the Montana Water Resources Board and revision, a draft Water Allocation study report was presented to the Yellowstone River Compact commission at Sheridan, Wyoming, on December 19, 1967. On the basis of this initial water allocation study, yield studies showed that the maximum yield from the Tongue River which could be developed from water allocated to Montana was 72,000 acre feet a year and a gross storage of 245,000 acre feet was required to develop that yield.

Following a presentation of the allocation and yield studies to the Board in Billings on January 4, 1968, further studies were made by the Board on the allocation study. Following a meeting between the Montana Water Resources Board Director and the Wyoming State Engineer on January 24, 1968, it was determined by the Board that the storage rights of the existing Tongue River Reservoir be considered as not being subject to allocation regardless of possible future changes of actual

use. The effective result of this change of interpretation was to increase the water which could be developed by Montana and therefore the yield of the project. Under this revised allocation it was determined that a maximum yield of 112,000 acre feet annually could be developed by providing some 450,000 acre feet of gross storage.

A revised draft of the Water Allocation study report was reviewed with the Board and with members of the legislative council on April 5, 1968 at Helena. The Water Allocation Study report was submitted to the Board in final form on April 22, 1968.

The Water Allocation Study presented two "allocations". The first adhering strictly to the compact provisions, particularly with respect to reservations of supplemental water, leads to conclusions which are believed unrealistic. The second "allocation" was made based on analysis and judgment of realistic future conditions in the Tongue River Basin. The Board concurred in Bechtel's recommendation that the project be sized on the basis of the "realistic allocation". The yield studies based on that allocation are described later in this report.

During the summer and autumn of 1967, field investigations were carried out to provide data for design of the increased reservoir, either by raising the existing dam, or by constructing a new dam downstream. Foundation explorations were carried out at the existing dam and at the Oxbow site, located as shown on Drawing No. 6694-11-003. Because of unfavorable foundation conditions at the Oxbow site, another site, called the Four Mile Creek site, was also explored. Borrow explorations were also carried out at this time to locate and obtain samples of earth construction materials.

During the fall of 1967 and the early winter of 1967-1968, design studies for raising the existing dam or constructing a new one downstream were carried out. Based on the initial allocation and yield studies, preliminary designs providing total storage of 245,000 acre feet were undertaken. During this period the Board determined that storage of water in Wyoming should be avoided. This criterion effectively limits the storage to about Elevation 3441, which is the approximate elevation of the Tongue River streambed at the State Line.

In January 1968, after preliminary designs had been well advanced, the revision of the allocation and yield studies required further substantial changes in the scope of the project. Studies of foundation conditions and raising the existing Tongue River dam indicated that only a moderate raise would be possible. The yield studies based on the revised and "realistic allocation" study have shown that some 450,000 acre-feet gross storage would be required for development of the 112,000 acre feet per year firm yield. Only about 140,000 acre feet of storage would be available at the existing dam site, yielding about 72,000 acre feet per year. The damsite near the Four Mile Creek confluence with the Tongue River is the furthest downstream feasible damsite before the Tongue River canyon opens out into a broader valley.

Therefore it is the site with the greatest storage potential without storing water above the State Line into Wyoming.

A dam at the Four Mile Creek site would store water to the same elevation as the existing dam raised to its greatest feasible height. However the Four Mile Creek site would provide substantially more yield. If the existing dam were raised, at an estimated direct construction cost at 1968 price level of about $4,000,000 and additional water needed at a later date, the raised dam would be inundated and the investment would not be fully recovered. Therefore, it was recommended to the Board that a dam be built at the Four Mile Creek site and raised later if necessary to provide greater storage and greater yield.

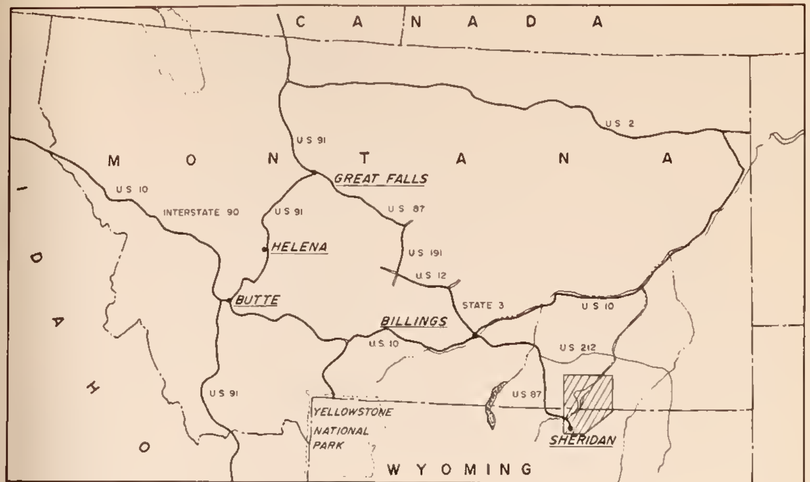
On April 5, 1968, the Board directed Bechtel to proceed with design of a dam at the Four Mile Creek site, later designated as the High Tongue River Dam. The Board directed that the dam have a maximum storage Elevation 3438, about three and one-half feet below the State Line streambed elevation. Although this will prevent storage of water in Wyoming, floods which may occur when the reservoir is nearly full, will cause ponding of water in Wyoming. The Storage Elevation 3438 will provide gross storage of 320,000 acre feet with a corresponding yield of 100,000 acre feet annually, part of which is for agricultural use under existing committments.

There is a possibility that a dam may be constructed for industrial purposes near the State Line in Wyoming. Such a development is considered reasonable because of physical feasibility of a damsite at that location and all Tongue River drainage in Wyoming would be tributary to such a reservoir. Such construction would make possible raising High Tongue River Dam if suitable arrangements could be made to back water up on the downstream side of the new dam. The Board therefore directed that the High Tongue River dam be designed so that it could be raised to storage elevation 3453, to provide 450,000 acre feet storage with a corresponding firm yield of 112,000 acre feet annually.

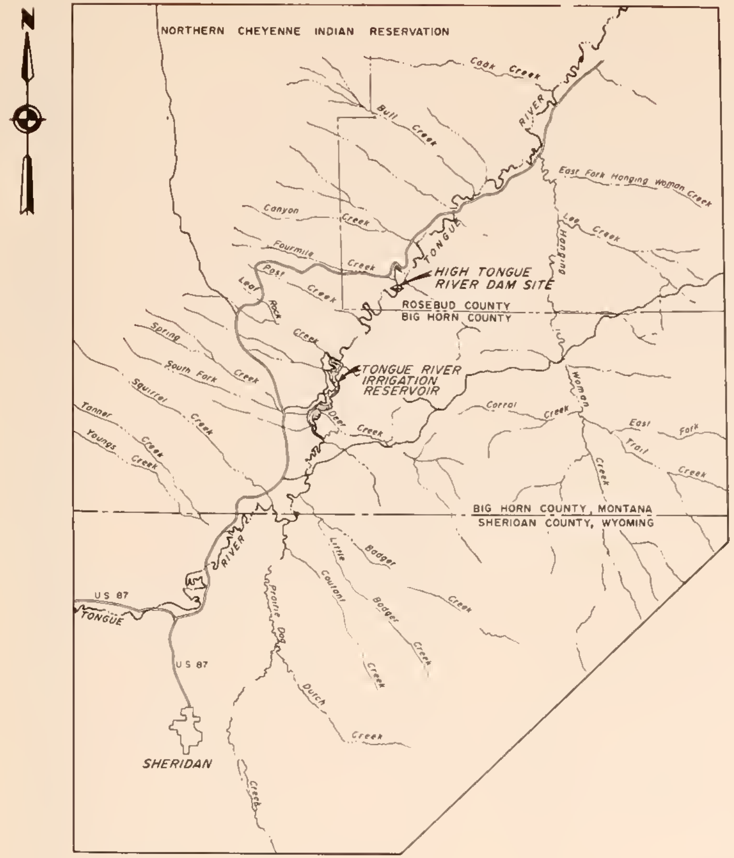
This report provides the basic design, data and construction cost estimates for the High Tongue River Dam. The yield studies, geology, construction materials, are described. The criteria for and design of the earth dam, spillway and outlet works are presented.

SUPPORTING DATA

Data which supports the design is presented in the supporting data volume. Topographic maps of the reservoir are presented. Included are calculations of storable inflow for the realistic allocation. The geological report on damsites, rock mechanics laboratory tests on the coal and soil test data are presented. Also included is a full treatment of the data on the existing Tongue River Dam, including preliminary raising design, a history with emphasis on seepage problems, construction drawings and photographs and reports on various grouting programs.



LOCATION MAP



VICINITY MAP

NO	DATE	REVISIONS	BY	CK	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
PROJECT LOCATION AND VICINITY MAPS

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED ______ DATE ______

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED ______ PROJ ENG'R RCH
DRAWN SHIMAURA MGR SP PROJ
CHECKED KMS MGR ENG'R

JOB No.	DRAWING No.	REV
6694	6694 - II - 001	


MONTANA
WYOMING
YELLOWSTONE
RIVER
MILES CITY
HIGH TONGUE RIVER DAMSITE
TONGUE RIVER IRRIGATION RESERVOIR
NORTH TONGUE RIVER
SOUTH TONGUE
TONGUE RIVER
LITTLE TONGUE RIVER
WOLF CR.
SOLDIER CR.
GOOSE CR.
LITTLE GOOSE CR.
SHERIDAN
PRAIRIE DOG CR.
HANGING WOMAN CR.
OTTER CR.
PUMPKIN CR.
TONGUE RIVER BASIN MAP
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
APPROVED
DATE
BECHTEL CORPORATION
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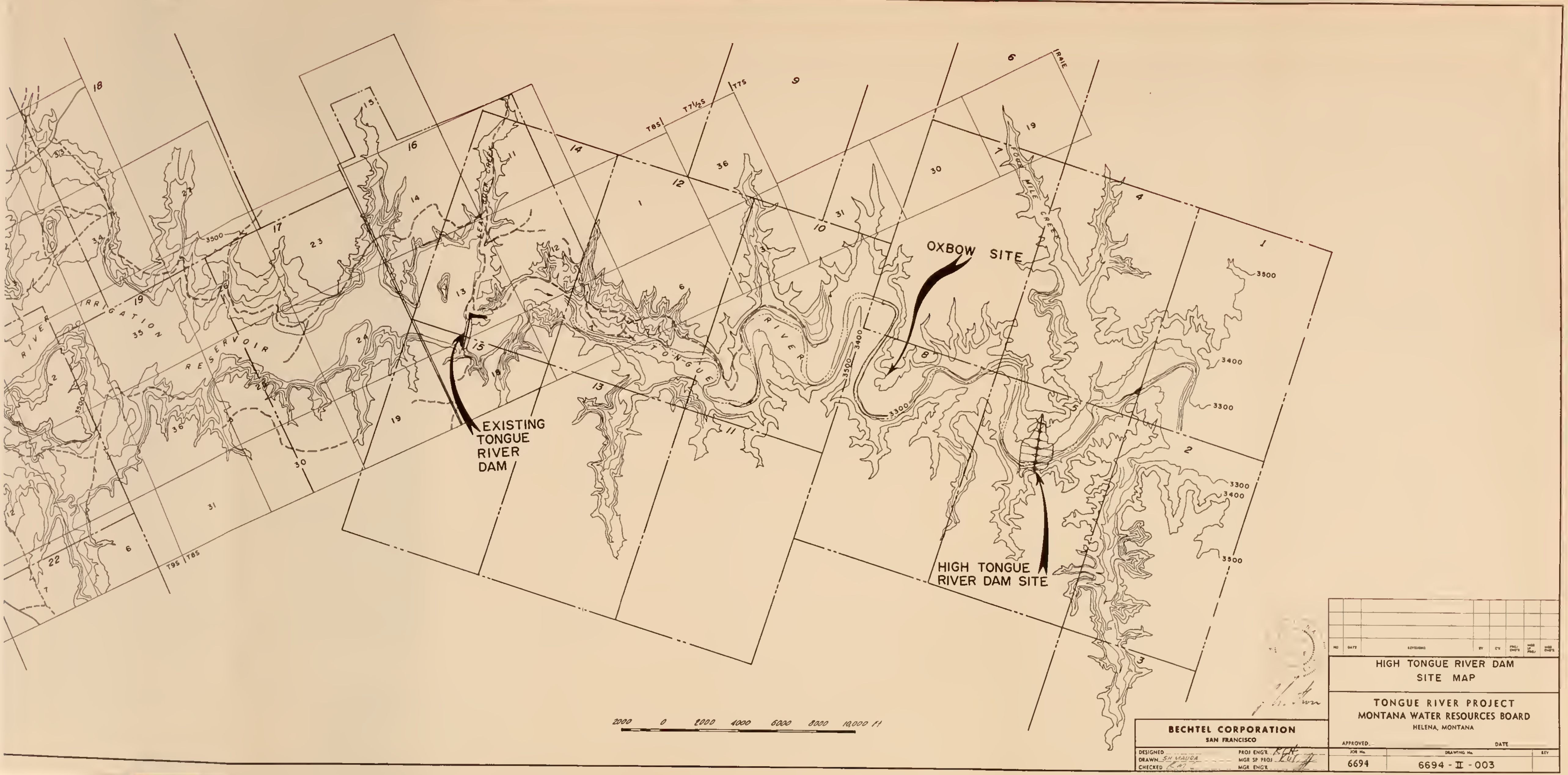
MONTANA
WYOMING
R39E | R40E
TONGUE
RIVER
PRAIRIE DOG CREEK
DECKER
TONGUE RIVER
IRRIGATION
RESER
R83W | R82W
T58N
R40E | R41E
T9S | T8S
3500



OXBOW SITE
EXISTING TONGUE RIVER DAM
HIGH TONGUE RIVER DAM SITE
TONGUE RIVER
RIVER IRRIGATION RESERVOIR
FOUR MILE CREEK
T8S
T7½S
T7S
T9S
R41E
3300
3400
3500
2000 0 2000 4000 6000 8000 10,000 ft
HIGH TONGUE RIVER DAM
SITE MAP
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
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III. WATER SUPPLY STUDIES

GENERAL

In order to determine the firm yield of the Tongue River Project and the correlated reservoir storage capacity,a series of studies was made. These studies were based on an allocation of water under the Yellowstone River Compact. First, the historical inflow to the project area was determined. Second, the probable future depletion of flow above the state line by Wyoming under the provisions of the Yellowstone River Compact was subtracted from the historical inflow. Third, downstream releases for prior adjudicated rights on the Tongue River were deducted from the inflow. Fourth, the remaining water, called the storable inflow, was analyzed on a time sequence basis to determine the variation of the minimum storable inflow with time. Fifth, the minimum storable inflow was analyzed against time, evaporation and storage in order to evaluate the correlated firm water yield and required storage.

The water supply studies for the Tongue River Project are based on the "Water Allocation Study" report which developed the historical sequence of unused and unappropriated flows which could be allocated to Montana. That report was submitted to the Montana Water Resources Board on April 22, 1968 by Bechtel Corporation. The yield studies are based on the "Realistic Allocation" described in that report.

YELLOWSTONE RIVER COMPACT

A number of major rivers - the Clarks Fork of the Yellowstone River, Big Horn River, Tongue River, and Powder River - flow north from Wyoming into Montana to join the Yellowstone River. Beginning in the 1930's the states of Montana and Wyoming appointed Commissioners to study and determine the apportionment of water of these rivers between the states. During the 1930's and 1940's negotiations led to the signing of compacts which were not ratified by the legislatures. However, in 1950 an agreement including North Dakota was reached and a compact was signed at Billings, Montana, on December 8, 1950. The compact was subsequently ratified by the legislatures of the various states and by Congress.

The purpose of the Compact is "to remove all causes of present and future controversy between said states . . . with respect to the waters of the Yellowstone River and its tributaries . . . to provide for an equitable division and apportionment of such waters, and to encourage the beneficial development and use thereof."

The Compact provides that all appropriative rights to beneficial uses of the water of the Yellowstone River System existing in each state as of January 1, 1950, shall continue to be enjoyed in accordance with the laws governing the acquisition and use of water under the doctrine of appropriation. Further, the Compact provides that, of the unused and unappropriated waters of the interstate tributaries of the Yellowstone River as of January 1, 1950,

there is allocated to each state such quantity of that water as is necessary to provide supplemental water supplies for the appropriative rights existing as of January 1, 1950. Such supplemental rights are to be acquired and enjoyed in accordance with the laws governing the acquisition and use of water under the doctrine of appropriation. In the Tongue River, the remainder of the unused and unappropriated water is allocated 60 percent to Montana and 40 percent to Wyoming.

Nothing contained in the Compact is to be so construed or interpreted as to affect adversely any rights to the use of the waters of the Yellowstone River and its tributaries owned by or for Indians, Indian tribes, and their reservations.

The Compact provides a relatively simple formula for determination of the percentage allocations. The quantity of unused and unappropriated water subject to allocation is to be determined on an annual water year basis measured from October 1 of any year through September 30 of the succeeding year. The quantity to which the percentage factors shall be applied through a given date in any water year shall be, in acre-feet, equal to the algebraic sum of:

1. The total diversion above the point of measurement for irrigation, municipal and industrial uses in Wyoming and Montana developed after January 1, 1950;

2. The net change in storage in all reservoirs in Wyoming and Montana above the point of measurement completed subsequent to January 1, 1950;

3. The net change in storage in existing reservoirs in Wyoming and Montana above the point of measurement which is used for irrigation, municipal and industrial purposes, developed after January 1, 1950;

4. The quantity of water that passes the point of measurement in the stream.

The point of measurement in the Tongue River is below the last diversion from the river above its confluence with the Yellowstone River.

HISTORICAL INFLOW TO THE TONGUE RIVER PROJECT

Inflow to the Tongue River Project is measured by the gage -"Tongue River at State Line." This gaging station was installed in 1960 but the record has been extended back to 1945 by use of the records from the gages "Tongue River at Tongue River Dam and Tongue River Reservoir End-of-Month Contents." This extended record was then modified as described in the "Water Allocation Study" report. First, the record was reduced to

reflect the existence of the 1966 level of rights throughout the entire period. This was done on the "Part 2 - Wyoming" sheets in the "Water Allocation Study".

FUTURE DEPLETION IN WYOMING

The modified historical record was further reduced to account for the use of supplemental and surplus water in Wyoming on the basis of the "Realistic Allocation". The record of flow at the State Line gage reflecting the 1966 level of rights and realistic development of surplus and supplemental water in Wyoming is developed on the "Part 2 - Wyoming" sheets under the "Realistic Allocation". Wyoming's forty percent allocation of the unused and unappropriated water in the Tongue River, reduced for the post-1950 rights satisfied, was also deducted from the inflow. Wyoming's 40% share of the unused and unappropriated water was determined on the "Part 3 - Unused and Unappropriated Water" sheets under the "Realistic Allocation". The total for any year was assumed to be used for industrial purposes with annual consumption of 90% or 7.5% in each of the twelve months.

REQUIRED RELEASES

The decreed rights downstream of the Tongue River Project total 414.9 cfs. In addition to 30 cfs decreed rights, 60 cfs have been allotted to the Northern Cheyenne Indian Reservation as an allowance for water supply for their reserved lands as described in the "Water Allocation Study" report. This total of 475 cfs of prior rights are active during the irrigation season - May through September.

In the non-irrigation months, releases are required for stock water and for prevention of ice jams. This release has historically been the inflow to the reservoir up to 10,000 acre feet per month (equivalent to 167 cfs continuously). The minimum release required for fish and municipal uses is understood to be 35 cfs. An October through April average release of 75 cfs is judged necessary to provide a live stream and prevent ice jams.

The yield studies were made for May through September release of the natural inflow up to prior rights of 342 cfs. 342 cfs is .72x475 cfs and reflects rediversion and reuse of return flows as demonstrated by the Use Factor developed in the "Water Allocation Study". The winter release used in the yield studies was the natural inflow up to 75 cfs.

STORABLE INFLOW

The water available for development by the Tongue River Project is taken as the historical inflow to the project as modified by future depletion in Wyoming and reduced by the required downstream releases. This remainder, called the storable inflow, is determined by the calculation described in the following step-by-step description and illustrated on Table III-1:

STORABLE INFLOW CALCULATION REALISTIC ALLOCATION:

Col 1 Year

Col 2 Month

Col 3 Flow - Tongue River at State Line - with 1966 Level of Rights, Surplus up to 220 cfs and Sheridan Canal - From Col 26 Part 2, Wyoming sheets in the Realistic Allocation.

Col 4 7.5% of The Annual Amount of Water Available for new Developments in Wyoming.

In the Realistic Allocation Study, the annual amount of water allocated to Wyoming under the Yellowstone River Compact was calculated. This was reduced by the amount of water used to satisfy Post 1950 rights in Wyoming. The remainder was considered to be used uniformly throughout the year and to be 90% consumed- 10% appearing as return flow. 7.5% is the monthly equivalent of a 90% annual consumption.

Col 5 Net Inflow to Tongue River Reservoir - Col 3 minus Col 4.

Col 6 Releases to Satisfy Downstream Rights.
Col 5 up to 342 cfs during May through September.
Col 5 up to 75 cfs during October through April.

Col 7 Storable Water - Tongue River Reservoir.
Col 5 minus Col 6.

MINIMUM STORABLE INFLOW - FIRM YIELD - STORAGE

An approximate method for relating firm yield, storage and evaporation was presented in "Design Drouth Criteria" by Robert S. Gooch; Journal of the Hydraulics Division, ASCE, Vol. 92, No. HY2, March, 1966. The procedure consists of determining the annual minimum storable inflow based on the smallest one month storable inflow, the smallest two consecutive month storable inflow, the smallest three consecutive month smallest inflow, etc., plotting these annual storable inflow values against the number of months represented, and drawing the lower envelope curve of the points. A digital computer program is used to calculate the R vs. N points from the chronological storable inflow record. The resulting points and curve are shown on Drawing No. 6694-111-001.

Using points on the lower envelope curve; time, storage, yield, storable inflow and evaporation are related by the basic equation:

$$Y = \frac{C}{N} + R - L$$

Where Y = firm yield in Acre Feet per year.

C = required active reservoir capacity in Acre Feet.

N = drought period in years.

R = storable inflow corresponding to the drought period (determined from the graph described above) in Acre Feet per year.

L = losses in Acre Feet per year.

An allocation of water between Wyoming and Montana could not be made for the years prior to 1945 because there was no continuous record of flow in the Tongue River at Miles City. A continuous record of flow in the Tongue River at the Montana-Wyoming state line was developed back to 1929 by using the Tongue River at Tongue River Dam and Tongue River Reservoir, End-of-Month Contents gages for the period 1939-1960, and the Tongue River near Decker gage for the period 1928-1938. This extended record was then adjusted to show the effect of the 1966 level of rights during the entire period. R vs. N curves were made for the periods 1929-1966 and 1945-1966 using the adjusted record on the basis of the 1966 level of development. The R vs. N curves were compared, and correlation factors to bring the 1945-1966 curve to the 1929-1966 curve were developed. These correction factors were then applied to the 1945-1966 "Realistic Allocation" R vs. N curve to extent its applicability to the 1929-1966 period.

The correction factors and the corrected curve are shown on Drawing No. 6694-III-001.

LOSSES

Although there will be seepage losses from the reservoir, it is judged that most seepage losses will reappear in the river downstream from the reservoir and therefore they will be small when compared with evaporation. For purposes of the yield studies, irrecoverable seepage losses are taken as 1000 Acre Feet per year for Stage I and 2000 Acre Feet per year for Stage II when more pervious strata may be below the higher storage level and head will be greater.

U.S. Weather Bureau records for the station at Terry, Montana, show pan evaporation of about 48 inches for the season May through October. Applying the normal .70 reduction factor for land vs. reservoir evaporation, this gives lake evaporation of 33.5 inches.

From the USWB map of normal annual Class A pan evaporation, the Tongue River Project area has about 40 inches of evaporation - 31 inches occurring in May through October.

Using an evaporation amount of 32.5 inches, and subtracting the normal seasonal precipitation of 12 inches, a loss of 20.5 inches is obtained. The average water surface area for the Tongue River Project is 3000 acres. Therefore the average annual evaporation is 5000 acre feet which was used in the firm yield studies.

Total annual losses used in the yield studies are 6000 acre feet for Stage I and 7000 acre feet for Stage II.

SILTATION

The original gross reservoir capacity (from original topography) in 1939 was 72,510 acre feet with 1900 acre feet in dead storage. A U.S. Bureau of Reclamation (USBR) siltation survey in 1948 found (by soundings) that the capacity had been reduced to 69,440 acre feet of which 1400 acre feet was dead storage. In that nine year period, some 340 acre feet per year of silt was deposited in the reservoir of which 275 acre feet per year was deposited in active storage.

The 1948 U.S.B.R. storage vs. elevation curve was used to develop the present total storage curve shown on Drawing 6694-III-002.

A siltation and dead storage allowance of 21,000 acre feet has been adopted in addition to the required active storage to provide silt storage through the year 2008 with some 600 acre feet of dead and silt storage remaining at that time.

It must be recognized that this siltation analysis is based on minimal data. After the increased Tongue River Reservoir has been in operation for some 15 or 20 years a siltation survey should be made as a check on reduction of storage.

ANALYSIS

A series of computations to determine the relationship between various storages and yields were made. The area and capacity curves are shown on Drawing No. 6694-III-002. The results of the yield and gross storage (including siltation and dead storage) calculations are shown on Drawing 6694-III-003.

DETERMINATION OF FIRM YIELD - OPERATION STUDY

In order to check the accuracy of the approximate method described above, a reservoir operation study was made using a computer program from Bechtel's program library. The agreement between the approximate method and the operation study was within 6%, well within the limits of accuracy of the data.

CONCLUSIONS

The analysis shows that a maximum of 112,000 acre feet per year of firm yield will be available for development based on the "realistic allocation" and full industrial use of Wyoming's share of the unused and unappropriated water. To develop this amount of firm yield, a gross reservoir storage of 450,000 acre feet is required which will provide for 12 years of carryover.

For the Stage I development of 100,000 acre feet per year of firm yield, a gross reservoir storage of 320,000 acre feet per year is required. The Stage I storage provides for ten years of carryover.

Part of the firm yield of the Tongue River Project is for downstream agricultural uses as provided by the existing Tongue River Irrigation Reservoir which will be inundated by the new reservoir.

RESERVOIR FILLING STUDIES

A study has been made to determine probabilities of filling the reservoir in various periods of time. The firm yield of the Stage I project has been based on beginning a critical drought period of ten years with the reservoir at full storage level. Therefore the reservoir must be filled before its operation can be considered as providing firm yield.

The 21 years of record from 1946 through 1966 were analyzed. Because it is not known when the reservoir will be constructed, it must be recognized that different conditions of flow may exist in the future due to upstream development. Therefore, three cases of water use assumptions were studied:

Case I: 1966 level of upstream development. Prior rights releases May through September: inflow up to 342 cfs. Winter releases: inflow up to 75 cfs. 30,000 acre feet assumed released to satisfy downstream agricultural contracts.

Case II: Same as Case I except that 37,000 acre feet of water is consumed by industrial development upstream in Wyoming.

Case III: Full "Realistic Allocation" development upstream in Wyoming. Prior rights releases May through September: inflow up to 342 cfs. Winter releases: inflow up to 75 cfs. 30,000 acre feet per year assumed released to satisfy downstream agricultural contracts.

The Stage I reservoir volume of 320,000 acre feet was filled, assuming that 30,000 acre feet were contained in the existing reservoir at start of filling.

The results of the filling probability studies are presented in the following Table:

PERCENTAGE PROBABILITIES OF FILLING STAGE I
TONGUE RIVER RESERVOIR

	1 Yr.	2 Yr.	3 Yr.	4 Yr.	5 Yr.	6 Yr.
Case I	9	48	78	96	100	100
Case II	6	32	53	74	90	100
Case III	0	11	30	53	80	100

A four to six year filling period therefore should be provided on the basis of the inflow Case which pertains at the time the project is financed.

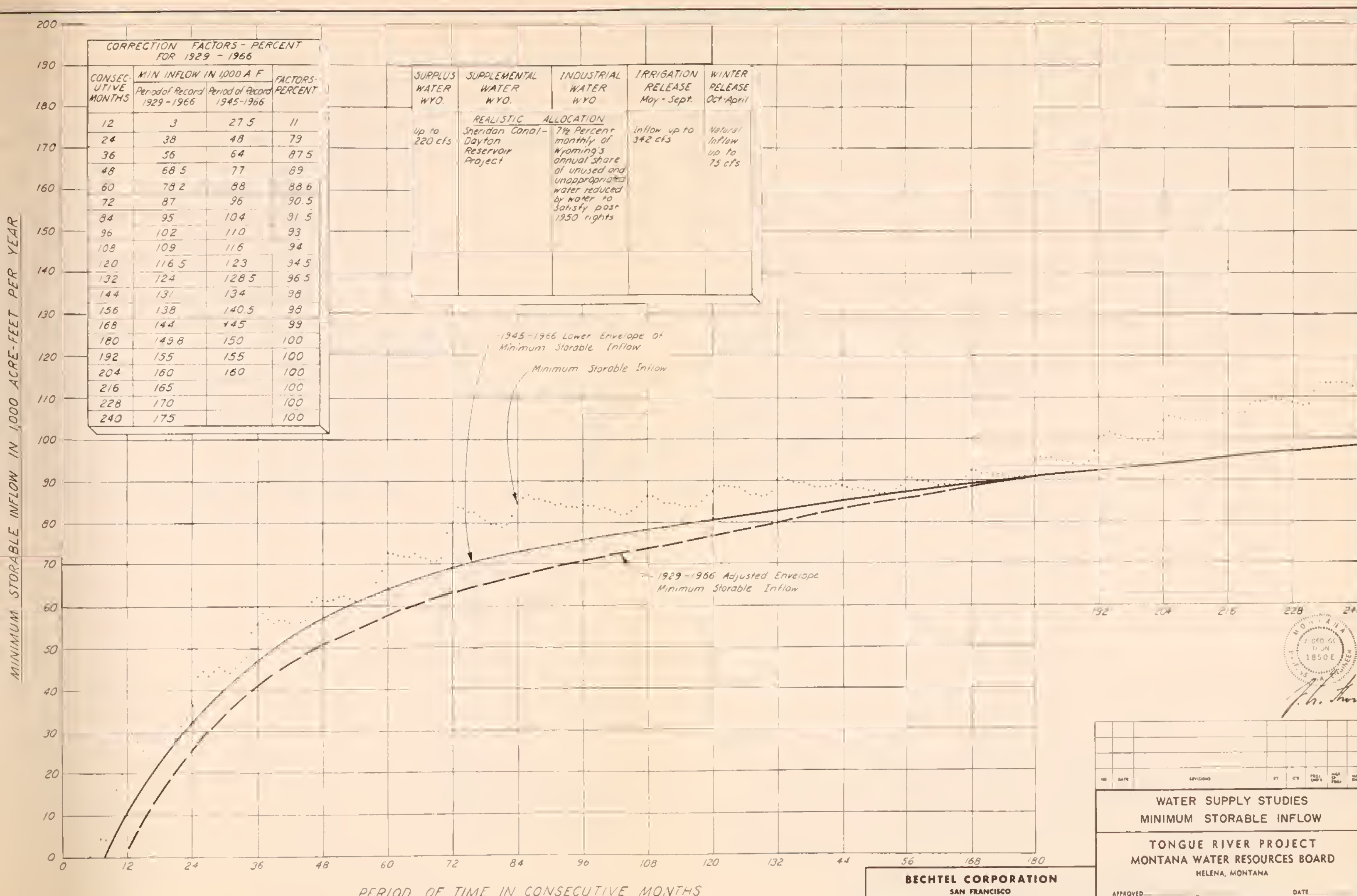
TONGUE RIVER PROJECT

342 and 75 cfs RELEASES

(1) Year	(2) Month	(3) Flow Tongue River at State Line with 1966 level of rights surplus up to 220 cfs and Sheridan Canal	(4) *7.5% of the annual amount of water available for new developments in Wyoming	(5) Net inflow to Tongue River Reservoir (3) - (4)	(6) **Releases to satisfy downstream rights; up to 342 cfs during the irrigation season and up to 75 cfs during the winter	(7) Storable Wate[r] Tongue River Reservoir (5) - (6)
		cfs	cfs	cfs	cfs	cfs
1962	Oct.	295	131	164	75	89
	Nov.	233	131	102	75	27
	Dec.	155	131	24	24	0
1963	Jan.	183	131	52	52	0
	Feb.	336	131	205	75	130
	Mar.	219	131	88	75	13
	April	366	131	235	75	160
	May	1286	131	1155	342	813
	June	2552	131	2421	342	2079
	July	394	131	263	263	0
	Aug.	116	131	0	0	0
	Sept.	147	131	16	16	0

*Water available is Wyoming's 40% share of U&U, less water used to satisfy Post 1950 rights

** 342 cfs at Tongue River Dam serves 475 cfs of rights along the Tongue River in Montana (including Indian rights)



CORRECTION FACTORS - PERCENT FOR 1929 - 1966

CONSECUTIVE MONTHS	MIN INFLOW IN 1,000 A F: Period of Record 1929-1966	MIN INFLOW IN 1,000 A F: Period of Record 1945-1966	FACTORS-PERCENT
12	3	27.5	11
24	38	48	79
36	56	64	87.5
48	68.5	77	89
60	78.2	88	88.6
72	87	96	90.5
84	95	104	91.5
96	102	110	93
108	109	116	94
120	116.5	123	94.5
132	124	128.5	96.5
144	131	134	98
156	138	140.5	98
168	144	145	99
180	149.8	150	100
192	155	155	100
204	160	160	100
216	165		100
228	170		100
240	175		100

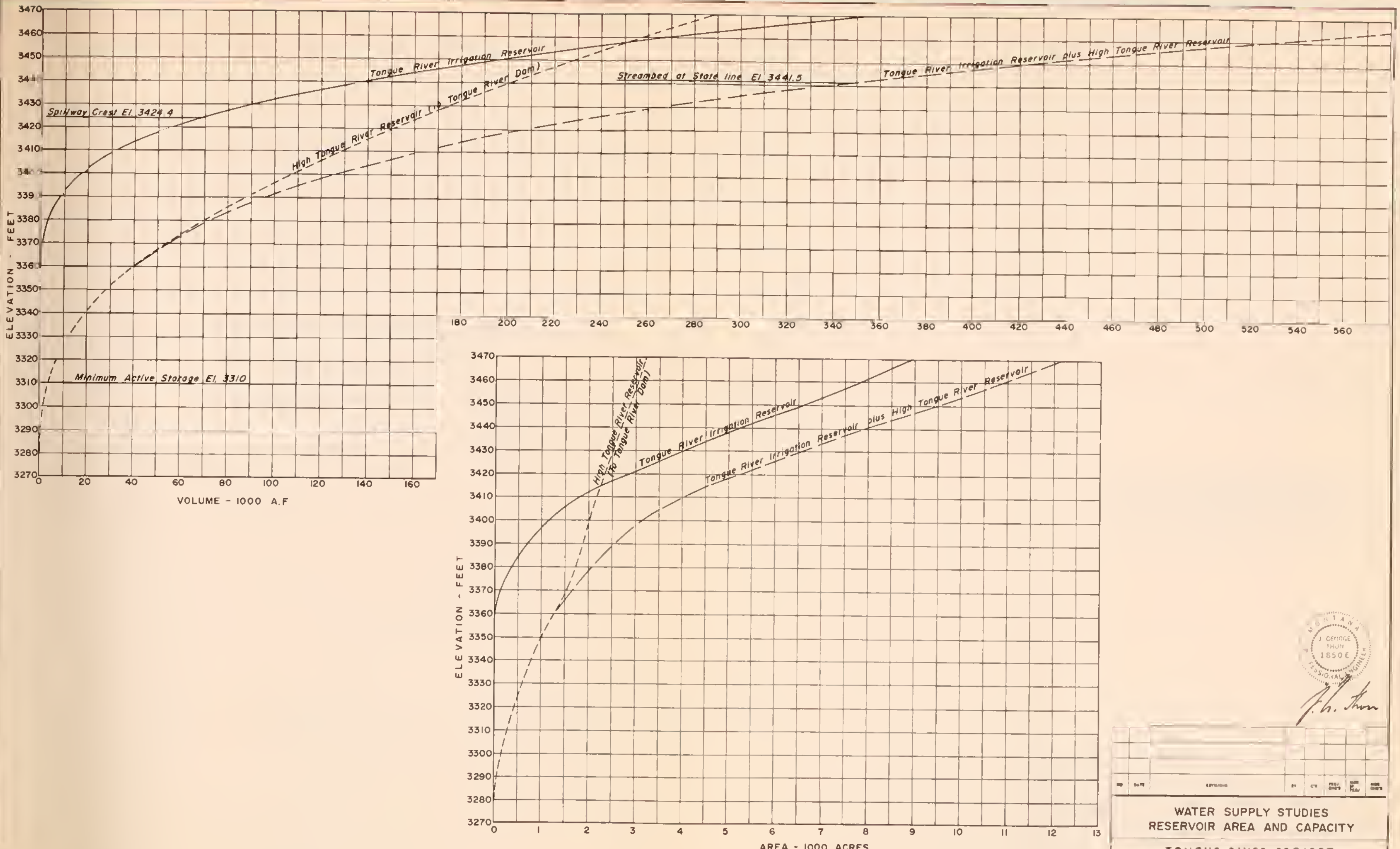
SURPLUS WATER WYO.	SUPPLEMENTAL WATER WYO.	INDUSTRIAL WATER WYO	IRRIGATION RELEASE May - Sept.	WINTER RELEASE Oct-April
	REALISTIC ALLOCATION			
up to 220 cfs	Sheridan Canal-Dayton Reservoir Project	7½ Percent monthly of Wyoming's annual share of unused and unappropriated water reduced by water to satisfy post 1950 rights	Inflow up to 342 cfs	Natural Inflow up to 75 cfs

WATER SUPPLY STUDIES
MINIMUM STORABLE INFLOW

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED
DRAWN
CHECKED
PROJ ENGR
MGR SP PROJ
MGR ENGR
APPROVED
DATE
JOB No. 6694
DRAWING No. 6694-III-001



BECHTEL CORPORATION
SAN FRANCISCO

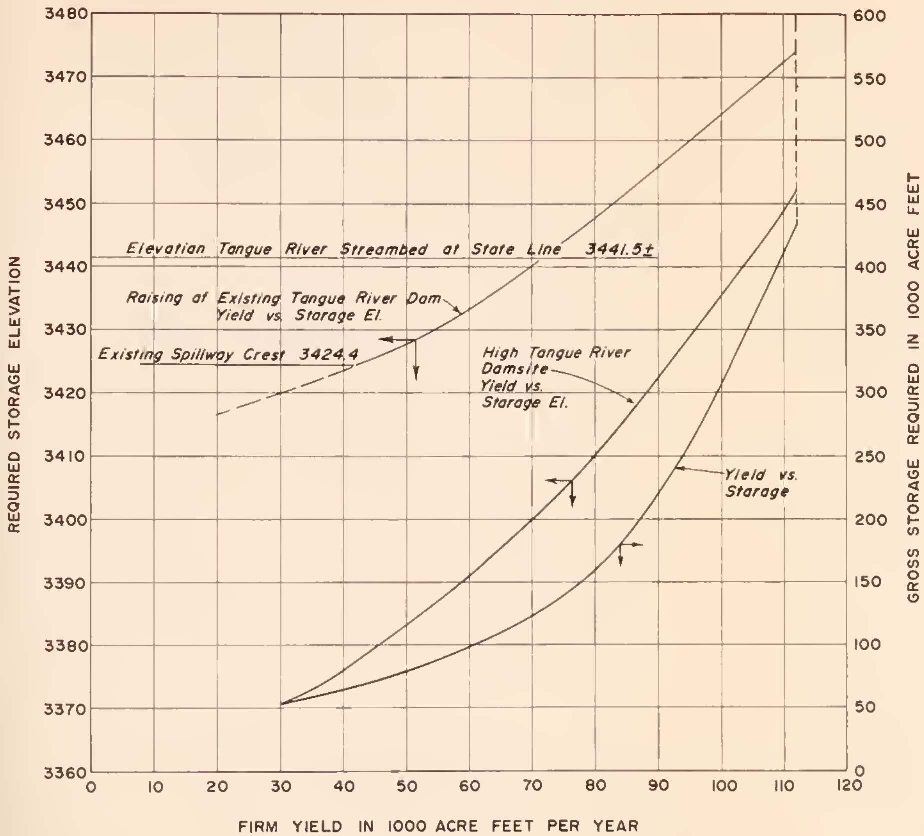
DESIGNED
DRAWN SHIMAURA
CHECKED RMS
PROJ ENG'R RCH
MGR SP PROJ
MGR ENG'R

WATER SUPPLY STUDIES
RESERVOIR AREA AND CAPACITY

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED
DATE

JOB No.	DRAWING No.	REV
6694	6694 - III - 002	



Firm yield and storage requirements based on Minimum Storable Inflow - Realistic Allocation Study - Downstream Releases 342 cfs Irrigation and 75 cfs winter flow

WATER SUPPLY STUDIES
YIELD - STORAGE - STORAGE ELEVATION

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED DATE

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED
DRAWN SHIMAURA
CHECKED

PROJ ENGR
MGR SP PROJ
MGR ENGR

JOB No. 6694
DRAWING No. 6694 - III - 003

IV. FLOOD HYDROLOGY

In order to provide data for design of the emergency spillway, a flood hydrologic study was made. This study included a review of the historical flood records and a development of the Probable Maximum Flood (PMF) and Standard Project Flood (SPF).

HISTORICAL FLOODS

U.S. Geological Survey gaging stations have been operated on the Tongue River in the vicinity of the project as follows:

Location	Dr. Area sq.mi.	Period of record
At State Line near Decker	1,477	1960-present
Near Decker	1,610	1928-38
Below Tongue River Dam	1,770	1939-present

The maximum flood recorded since 1960 at the State Line station was 6,080 cfs on June 16, 1963. The flood of June 2, 1929, with a peak discharge of 7,220 cfs, was the highest at the station near Decker from 1928 to 1938. At the station below the dam, the maximum flood since 1939 occurred on June 5, 1944, when a peak discharge of 6,180 cfs was observed.

Noteworthy floods prior to the period of record occurred in June 1908 and June 1916, but the discharges of these floods are not known.

FLOOD OF JUNE 1964

On June 7-8, 1964, a very large rainstorm occurred over northwester Montana (10). This storm was typical of other large rainstorms which have occurred along the eastern flanks of the northern Rocky Mountains. Because of its significance and because a similar storm could be expected anywhere along the mountain front, it has been used for development of the PMF.

PROBABLE MAXIMUM FLOOD

Criteria. The probable maximum flood inflow to the Tongue River Reservoir is based on the transposition and maximization of the June 7-8, 1964, storm over Northwest Montana.

PROBABLE MAXIMUM PRECIPITATION

To transpose the storm over the Tongue River basin above Tongue River Dam, the isohyetal map of the storm of June 7-8, 1964, was used.[8] This isohyetal map was oriented in such a way that the maximum average precipitation was obtained over the drainage area of 1740 square miles. Care was taken not to rotate the storm more than 5°. By planimetering

areas between isohyets an average precipitation of 7.35 inches over the drainage area was calculated. A coefficient of 1.35 was used to adjust the storm to maximum conditions.(7)(6) The transposed and maximimized storm would have a total maximum probable precipitation in 36 hours of 1.35 x 7.35 = 9.92 inches. Using the same depth-area-duration as observed for the storm of June 7-8, 1964, the 9.92 inches of probable maximum precipitation was distributed as follows:

Time (Hours)	Accumulated Depth (Inches)
1	0.71
3	1.78
6	3.24
9	4.68
12	6.31
15	7.10
18	7.99
24	8.96
30	9.55
36	9.92

UNIT HYDROGRAPH - 3 HOURS DURATION

Due to the great similarity in climatic and topographic conditions between the drainage area above existing Tongue River Dam and the Hole-in-the-Wall drainage area, the lag curve developed by the Bureau of Reclamation was used, as well as the dimensionless unit graph for the Tongue River near Dayton.(5)(6)(1) The final 3-hour unit graph was obtained following the procedure described by the Bureau of Reclamation.(4)

INFILTRATION

A retention rate of 0.25 inches per hour was used in the determination of the excess precipitation. Due to the similarity in soil, cover, and topography between the Hole-in-the-Wall basin and the drainage area above the existing Tongue River Dam, the same retention rate was used for both basins.

DESIGN INFLOW FLOOD HYDROGRAPH

Figure IV-1 shows the design flood at Tongue River Dam based on the design 36-hour rainfall, a uniform retention rate of 0.25 inches per hour and the three-hour unit hydrograph. This event is characterized by a peak discharge of 183,200 cfs and a total volume of 346,700 acre-feet. The increments of excess rainfall were re-arranged by trial to produce the maximum flood peak. The base flow of 3420 cfs, as used in the final computation of the inflow design flood, was obtained from analysis of recorded floods in the Tongue River basin.

SNOWMELT ANALYSIS

For analysis of snowmelt, the maximum floods in the Tongue River above the Tongue River Dam were selected. Three stations on the Tongue River were chosen as most representative of the basin. Due to the difference in areas above the stations, the relationship was developed between drainage area and snowmelt volume for a three-day period. By checking the daily precipitation records for the Sheridan station, the straightline corresponding to May, 1947, was selected as the best correlation factor in the snowmelt computation. (2) (3) (10) (9) Figure IV-2 shows the snowmelt studies.

ENVELOPE CURVE

Using the envelope curve for peak discharge in the Missouri River basin, developed by the Bureau of Reclamation, (5) the reading of the curve at 1740 square miles indicated a peak discharge of 70,000 cfs, which is 38.2 percent of the probable maximum peak flood.

STANDARD PROJECT FLOOD

A standard project flood (SPF) was developed and found to have a peak inflow of about 87,000 cfs.

The SPF when routed through the reservoir was found to have a peak outflow of 44,000 cfs.

TAILWATER RATING CURVE

Figure IV-3 shows the tailwater rating curve for the Tongue River immediately downstream from the Project site. The tailwater ratings were developed from field survey data which has been collected from a 2.5 mile downstream reach. A high and a low Manning's n value was used in both the main channel and the overbank.

These values represent the extremes of practical values which might occur in the river, and were assumed to be:

	High n	Low n
Main channel	.035	.028
Overbank	.060	.040

REFERENCES

1) U.S. Bureau of Reclamation, "Memorandum on Inflow Design Flood Study -- Hole-in-the-Wall Dam Site -- Powder River Basin, Wyoming," March 9, 1965.

2) United States Weather Bureau: Climatological data, "Daily and Hourly Precipitation Data."

3) United States Geological Survey, Surface Water Supply Papers, Part 6-A, "Missouri River Basin Above Sioux City, Iowa."

4) U.S. Bureau of Reclamation, "Design of Small Dams," 1965. Chapter 2, Flood Studies.

5) U.S. Bureau of Reclamation, "Feasibility Inflow, Design Flood Study for Hole-in-the-Wall Dam Site," from James No. Horn, Regional Project Development Engineer, 2/2/65.

6) U.S. Bureau of Reclamation, "Memorandum on Revised Design Storm -- Hole-in-the-Wall Dam Site -- Powder River Basin -- Wyoming," November 2, 1964.

7) Data on the June 7-8, 1964 Storm in Northwest Montana in the Headwater Drainage of the Missouri River, furnished by Harold Grout, USBR, Denver.

8) "Isohyetal Pattern Storm of June 7-8, 1964 Northwestern Montana," Received 6/27/67, from USBR, Denver.

9) United States Geological Survey, Surface Water Records of Montana.

10) U.S. Department of Commerce, Weather Bureau, "Climatological Data," Wyoming.

11) "Floods of June 1964 in Northwestern Montana",U.S. Geological Survey, Water-Supply Paper 1840-B.

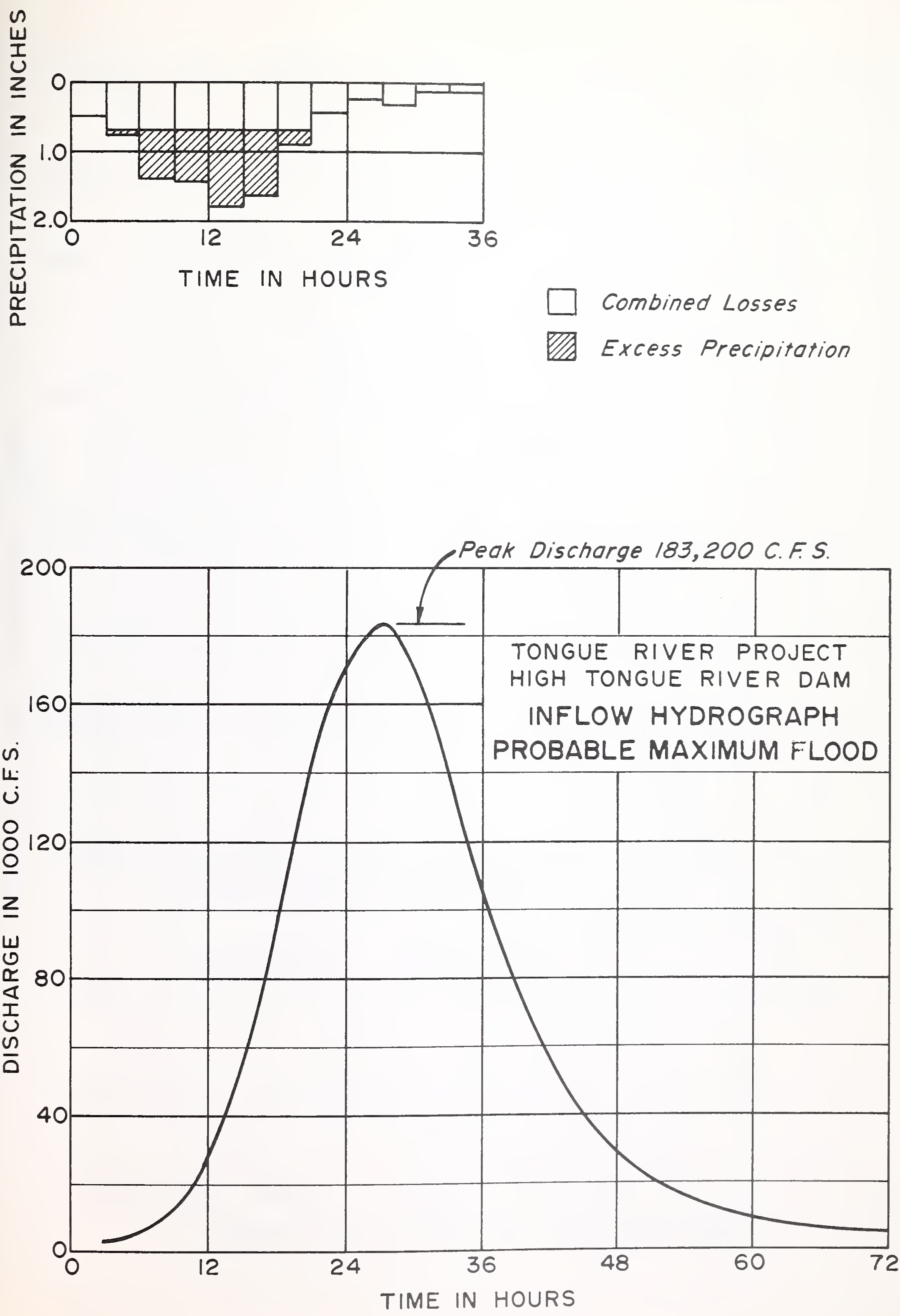

PRECIPITATION IN INCHES
0
1.0
2.0
0
12
24
36
TIME IN HOURS
Combined Losses
Excess Precipitation
Peak Discharge 183,200 C.F.S.
TONGUE RIVER PROJECT
HIGH TONGUE RIVER DAM
INFLOW HYDROGRAPH
PROBABLE MAXIMUM FLOOD
DISCHARGE IN 1000 C.F.S.
200
160
120
80
40
0
0
12
24
36
48
60
72
TIME IN HOURS

FIGURE IV - I

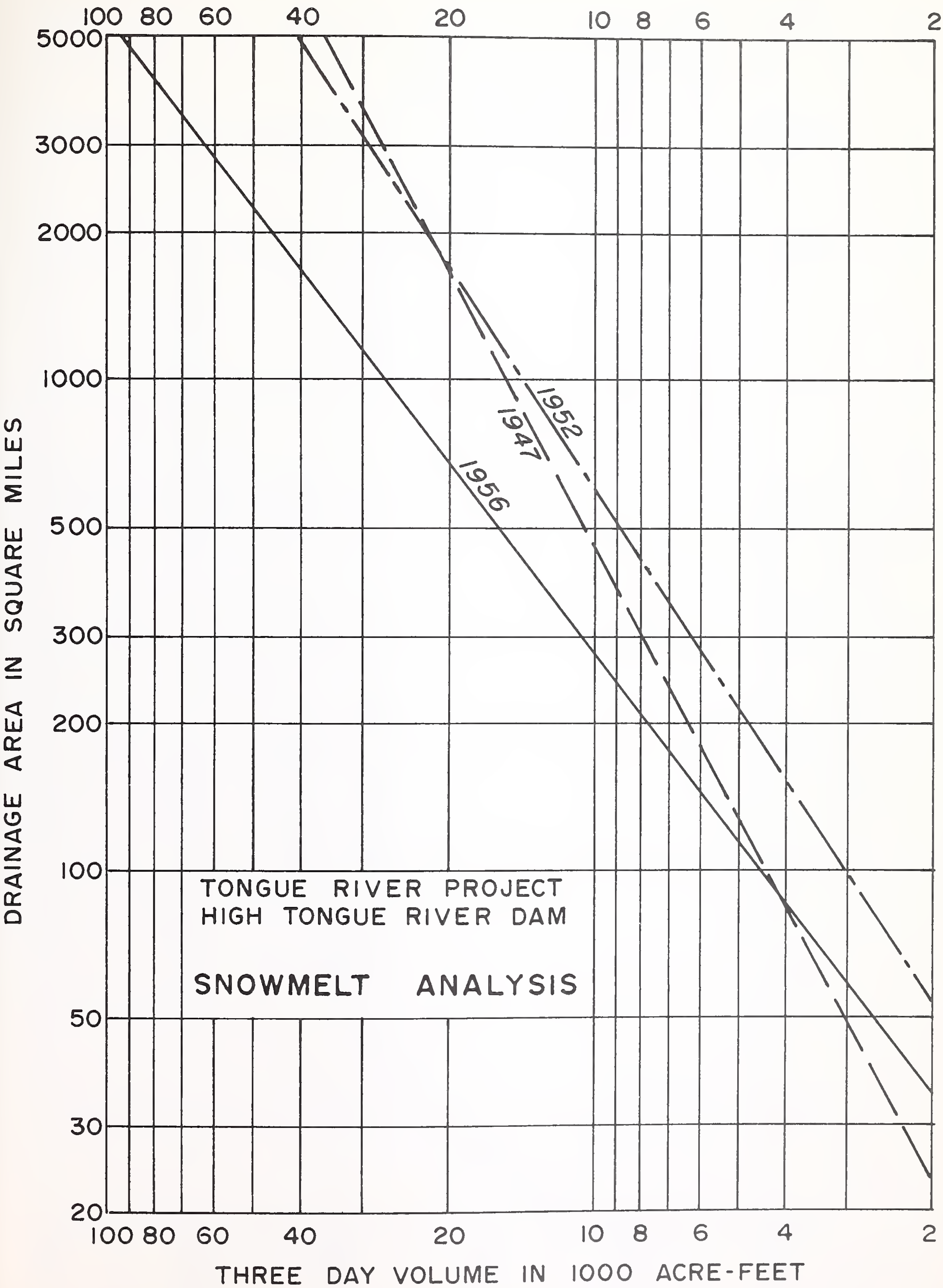
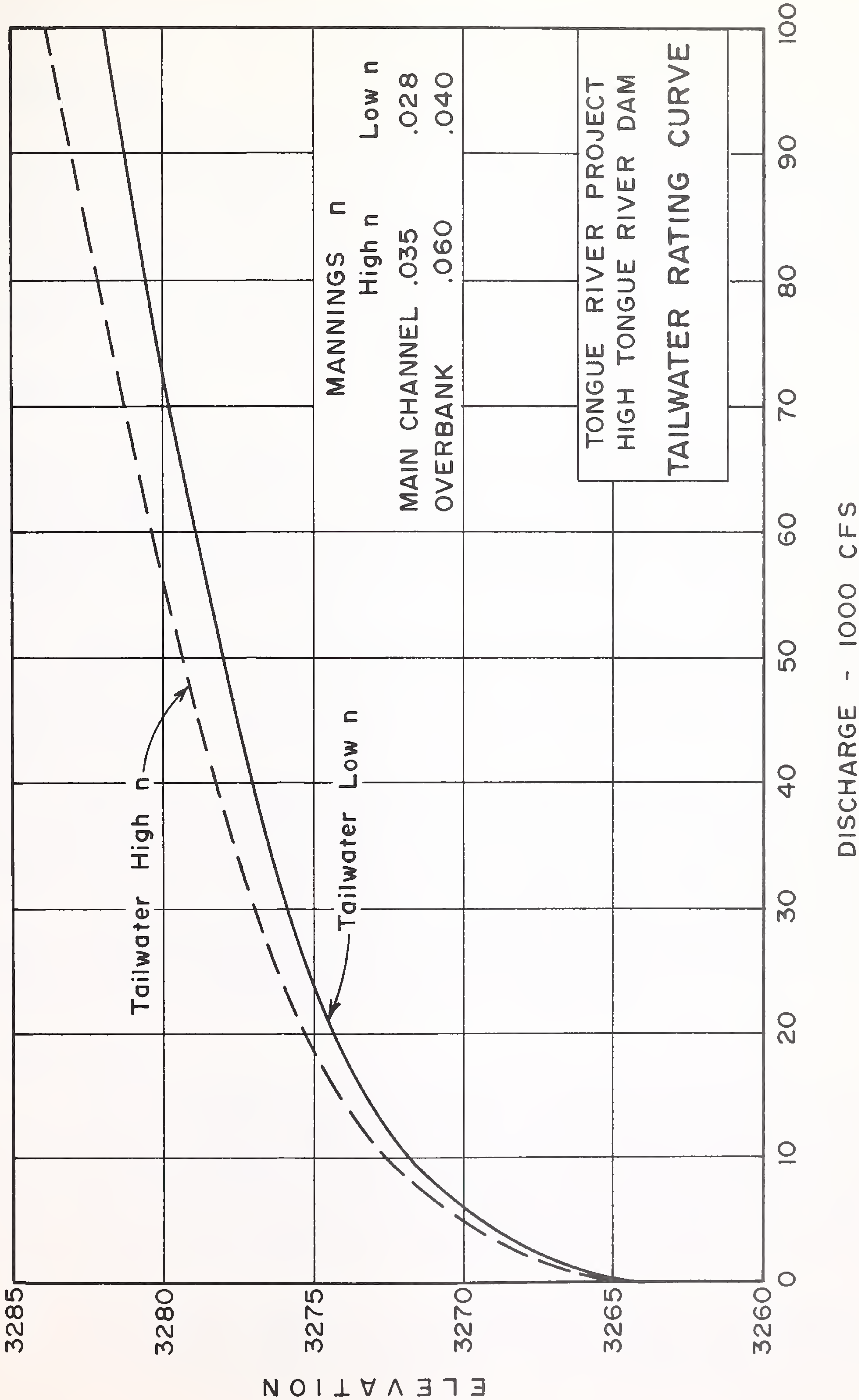

TONGUE RIVER PROJECT
HIGH TONGUE RIVER DAM
SNOWMELT ANALYSIS
1952
1947
1956
DRAINAGE AREA IN SQUARE MILES
5000
3000
2000
1000
500
300
200
100
50
30
20
100 80 60 40 20 10 8 6 4 2
THREE DAY VOLUME IN 1000 ACRE-FEET

FIGURE IV - 2



TONGUE RIVER PROJECT
HIGH TONGUE RIVER DAM
TAILWATER RATING CURVE
MANNINGS n
High n Low n
MAIN CHANNEL .035 .028
OVERBANK .060 .040
Tailwater High n
Tailwater Low n
ELEVATION
3260
3265
3270
3275
3280
3285
DISCHARGE - 1000 CFS
0
10
20
30
40
50
60
70
80
90
100

FIGURE IV - 3

V GEOLOGIC SUMMARY

INVESTIGATIONS

The geological explorations for the Tongue River Project were carried out in two phases. The first phase, conducted during the summer and fall of 1967, explored the general geology of the project area and site geology at the existing Tongue River Dam and two new downstream sites. After determination of project storage requirements and adoption of a plan for development at the Four Mile Creek site, a second phase of specific site geological studies was made for the High Tongue River Dam in the summer of 1968. These second phase studies were made to develop additional specific design data for that dam.

GENERAL GEOLOGY

The Tongue River is one of many rivers that flow north and northeastward from the northwest trending Continental Divide in western Montana and northwestern Wyoming. It originates in Wyoming on the northeast flank of the Big Horn Mountains, a vertically uplifted fault block trending northwestward across the Montana-Wyoming border. After leaving the Big Horn Mountains, the river meanders across the Great Plains Province to its confluence with the Yellowstone River near Miles City, Montana.

The surface of the Great Plains Province in the vicinity of the Tongue River Project is composed of well stratified sedimentary rocks of continental origin deposited during erosion of the ancestral Rocky Mountains. These sedimentary rocks are part of the Fort Union Formation which is Eocene in age.

Post-Eocene mountain building resulted in uplift and formation of the Big Horn Mountains. The Tongue River came into being and began eroding its way through the sedimentary rocks until presently it has downcut several hundred feet below the original plain and formed the Tongue River valley.

The Big Horn Mountain uplift upwarped the western edge of the Fort Union Formation and other sedimentary units, but the deformation did not affect the beds in the vicinity of the Tongue River dam sites. These strata are essentially flat-lying, unfolded, and unfaulted.

LOCAL GEOLOGY

From the Tongue River Dam to Four Mile Creek, the Tongue River has cut into the Fort Union Formation forming a valley from 100 to 350 feet deep and about 1300 feet wide. The strata of the Tongue River Member of the Fort Union Formation are well exposed in steep cliffs along the river and consist primarily of siltstone, sandstone, and an unusual sequence of baked sandstone and shale and some coal beds. Several coal beds in the siltstone unit are traceable for some distance, but thicken and thin along their outcrop.

The weathered exposures of sandstone are typically light yellow to buff and the siltstone is light gray. Cores of unweathered sandstone are buff to light gray and the siltstone is gray to dark gray.

The Tongue River Member is a continental deposit and possesses the sedimentary features common to sediments deposited under intermittent, torrential conditions. Features such as variation in thickness within a relatively short horizontal distance, pinching out of strata, cross bedding, and cut-and-fill structures are present at many places along the cliffs. Rock units at the three sites investigated generally showed consistency in thickness and elevation of particular beds but differences were observed.

COAL BEDS AND BAKED ROCK

The portion of the Tongue River valley studied lies in the northward extension of the Sheridan coal field. The coal is sub-bituminous with several beds being of commercial thickness and quality. These beds crop out along the cliffs of the valley and are easily recognized.

A unique bedrock feature in and around the Tongue River valley is the presence of prominent, resistant, cliff forming exposures of baked sandstone and shale. These rocks are brick red to salmon color as a result of baking from the burning of underlying coal beds. Sandstone beds have been altered in color and hardness but are still recognizable as sandstone. The siltstone beds have been hardened in some cases to porcellaneous shale and fused to slag. The baked rocks are locally referred to as "clinker" and "scoria", but the majority of the rock is recognizable as sandstone and shale.

The burned coal left voids that induced collapse of the overlying baked rocks producing collapse breccia. Cooling of the baked rocks produced contraction joints and horizontal partings along incipient bedding in siltstone which furthered breakdown of the rock. Because of the many fractures and joints the baked rocks are extremely permeable, but yet resistant to erosion because of their hardness.

The coal fires burned at the outcrops and where overburden was relatively thin, large surface areas were baked, but where overburden was thick, the baking extended less far back into the hill, but still often for several hundred feet. The vagaries of such baking are exhibited by rapid lateral change from baked to unbaked rocks.

The strata dip south beneath the floor of the valley. The local coal beds with engineering and geologic significance to this study are the Canyon bed, the underlying Wall bed, and several thin local beds between these two main beds. In exposure these beds have been burned and have been replaced by baked rock. However, where burning did not take place, as in the subsurface, the beds are still fresh coal. The Wall bed dips beneath the Tongue River just north of the Four Mile Creek site and is not exposed from there to the existing dam. The thick coal bed encountered in DH-1 at the High Tongue River dam site and DH's 3,5,6, 7 and 8 at the Oxbow site, is believed to be the Wall bed. The greatest thickness of this bed, now baked rock, in exposures north of Four Mile Creek is 32 feet, but where penetrated in drill holes at the Oxbow site it is 54 feet of coal and 60 feet of coal beneath High Tongue River Dam Site. To the north of Four Mile Creek the bed thins and eventually becomes several thin beds separated by siltstones.

Three to four local beds ranging in thickness from one to four feet are present in the vertical interval of 150 feet above the river surface and whether these local beds are continuous from the existing Tongue River dam to Four Mile Creek is not certain, but beds having approximately the same elevation and thickness are found at the three sites.

The Canyon bed is baked in exposures which rim the valley and is easily recognized by its brick red color. The bottom of the Canyon bed is generally about elevation 3450 to 3500.

NATURAL GAS SEEPS

Residents along the river in the vicinity of the dam sites report seeps of natural gas bubbling up through the river. The bubbling is especially noticeable during low stands of the river when the water is less turbulent and when the river is frozen over. The gas has been trapped in small containers and when ignited, burns with a blue flame.

Five locations were cited where natural gas has been reported in the river:

1. Near the U.S.G.S. stream gaging station below the dam.

2. Near Mr. Lee's house at his ranch.

3. Mr. Thompson's meadow.

4. Near the old water wheels at the Oxbow site.

5. At High Tongue River Dam site - Drill holes 104 and 105.

HIGH TONGUE RIVER DAM SITE

Physiography. The site is about 6000 to 7000 feet upstream of the confluence of Four Mile Creek and the Tongue River. The valley floor is from 700 to 1200 feet wide and is flanked on the left by two terrace levels reaching as high as 125 feet above the valley. On the right 40 to 45 degree slopes as high as 300 feet form the abutment. The sequence of bedrock units consists of interbedded sandstone and siltstone.

Geologic Exploration. The geologic exploration consisted of: (1) study of 1967 aerial photographs; (2) subsurface mapping at a scale of 1" = 100', shown on Drawing 6694-V-007; (3) drilling twelve exploratory NX core holes; and (4) the measurement of five stratigraphic sections, and the drilling of fourteen seven-inch auger holes.

All holes at High Tongue River Dam site, except at the right abutment (DH-1, DH-2 and DH-4), were provided with a 1-1/2 inch diameter coupling and plug, set in a concrete plug at the top of the hole. These couplings mark the hole locations for future use.

Stratigraphy. The uppermost rock unit is baked sandstone and shale which has broken down to form talus and debris aprons at the base of the unit. Underlying the baked rock unit is a siltstone unit containing some minor coal beds which in turn are underlain by a massive sandstone sequence. Beneath this, for the total depth drilled is another siltstone

unit which contains a 14-foot thick coal bed as found at the right abutment (DH-1).

The stratigraphy is illustrated on drawings 6694-V-008 and 008A.

Lithologic Units.

Alluvium. Exploratory drilling indicates that the silty sand and gravel in the channel section is as thick as 61 feet.

Terrace Deposits. Two nearly flat terrace surfaces are present at 75 and 125 feet above the valley floor on the left side. Exploratory drilling indicates that these sand and gravel deposits range from 10 to 20 feet thick.

Landslides. Several slope failures exist at the Four Mile Creek site, the most prominent of which is a landslide mass in the vicinity of DH-2. Geologic Section A-A' on Drawing 6694-V-008 shows a sequence of siltstone and coal in a stratigraphic position that should be occupied by massive sandstone. There is a seep near the upstream end of the slide area. Approximately 35 feet of talus and debris were encountered at the left abutment in DH-6. Other slope failures mapped in the vicinity indicate that several types of slope failures have occurred near the site.

Bedrock. Sedimentary rocks at the proposed site dip about 5 degrees south. The uppermost unit is baked sandstone and shale. Underlying this, from top to bottom, the strata are: siltstone containing minor coal beds, massive sandstone, and siltstone with sandstone interbeds and two thick beds of coal.

The dam abutments will be generally on the siltstone-coal and massive sandstone units. These units are generally weathered to depths ranging between 20 and 30 feet. Below the weathered zone, the rock contains relatively tight joints. The channel section will be in alluvium which is in direct contact with coal and/or siltstone.

Geologic Structure. The geologic structure is uncomplicated but there is a south and southwest dip consistent with the southward dip of such marker beds as the Wall coal. No faults or folds are known to exist at the site.

Prominent near-vertical joints control the shape of the prominent cliff. Joints and fractures in the cores are less frequent and tighter than in core from other sites.

Left Abutment. The base of the highly permeable baked rock is obscured by talus and slope wash but DH-6 encountered siltstone bedrock at elevation 3408 after going through talus and baked rock as determined by cuttings. Since no core was recovered from this interval, it is impossible to tell whether the baked rock is in place or is talus. Preconstruction drilling is required to clarify this question.

The gravel and sand terrace deposits are underlain, in descending order, by siltstone-coal and massive sandstone.

River Section. The 700 to 1200 foot wide valley floor is underlain by 27 to 61 feet of alluvium as determined in DH-3 and DH-101 respectively.

The underlying bedrock is interbedded siltstone and sandstone with layers of coal as thick as 57 feet. (DH-103). The depth to ground water ranges from 10 to 18 feet (July 1968).

Right Abutment. In the right abutment hill the base of the permeable baked rock is above the proposed second stage spillway crest elevation and reservoir seepage should not occur through this rock.

The massive sandstone in DH-4 appears to be good foundation rock.

Pressure Tests. Pressure tests show that water losses in the weathered rock were 20 to 30 gpm per 20 foot test increment using 1 pound of pressure per foot of hole. There was essentially no water loss in the unweathered rock.

Coal Beds. Several core holes, drilled in the river section area, encountered coal as shown on Geologic Sections A-A', B-B', and F-F'. The intervals of coal in the holes ranged from 31 to 57 feet although the greatest thickness of the coal may be 60 feet plus or minus 5 feet. Correlation of logs of all holes in this area is somewhat difficult as the bedding is lenticular and abrupt facies changes have occurred. Channel-cutting was probably taking place contemporaneously with, or just after, deposition of materials other than carbonaceous sediments. Examples of this channel cut-and-fill process have been observed on Tongue River upstream from the existing dam. Lensing and thinning of bedding can be seen in the right abutment at the Four Mile Creek site. It is not believed that faulting has caused the differences in elevation of similar lithologies as no surface evidence has been found to substantiate such a hypotheses.

A deep coal layer 57 feet thick was found in DH-103 at a depth of 133 feet below the ground surface in the river channel section.

It is improbable that a thick coal stratum, along Geologic Section A-A', is present from channel centerline westward to the left abutment. Coal is present under the right channel, and right abutment as well as upstream from the axis. In most holes encountering coal, alluvium is in direct contact with the coal and the original upper surface of the coal has been eroded away. Evidence for this is the large percentage of coal debris disseminated within the alluvium.

The lenticular nature of the bedrock strata is illustrated by Geologic Sections A-A', B-B' and Figure V-1. The same type of lenticularity downstream of High Tongue River dam axis is suggested by drill holes showing bedrock other than coal underlying the channel deposits.

The cores obtained in 1967 were re-examined in 1968. Some of the strata previously logged as siltstone and closely associated with the coal beds had slaked in the exposed core boxes. A sample was tested and found to be clay shale.

SEISMICITY

The area of the Tongue River is not considered to be seismically active. During the period of record from 1852 to 1966, only one earthquake of intensity V or greater has had an epicenter within a 75-mile radius of the dam. This was an intensity V shock in 1925 with its epicenter about 38 miles south of Sheridan, Wyoming.

The Seismic Regionalization Map, Drawing 6694-V-010, in the supporting data shows the eastern half of Montana to be in a maximum intensity zone of VII which is one of the lower in the country.

The Seismic Probability Map, Drawing 6694-V-011, in the supporting data shows the site to be in Zone 1 where damage would be minor.

The closest, most recent major earthquake occurred at Hebgen Lake on August 17, 1959. The shock had a Modified Mercalli intensity of X at the epicenter which was located about 225 miles west of the Tongue River Dam.

An earthfill dam in the Tongue River area would sustain little damage from an earthquake of intensity VII whose epicenter was in the dam area. The probability of such a quake occurring is satistically low. It is recommended that a horizontal seismic factor of 10% be used for design.

GEOLOGIC CONCLUSIONS

The geologic conditions present at High Tongue River Dam have been explored and were found to be suitable for construction of a dam of the proposed height.

The foundations are relatively strong. However, strata of baked rocks are highly pervious and coal layers are expected to be moderately pervious. Therefore seepage control must be provided for both these materials. It is anticipated that a combination of grouting and downstream drainage including relief wells, will provide effective seepage control.

The lithologic characteristics of the rock indicate generally low permeability. But since there are local more permeable strata a grout plan and procedure was designed to reduce this permeability to an acceptable minimum.

The cost estimate for grouting is based on the assumption that grout holes 70' - 140' deep with initial spacing of 10 feet and closer spacing of 5 feet and a grout acceptance of about 1 cu.ft. of cement to each lineal foot of grout hole will be adequate. This figure does not include a grout extension into either abutment.

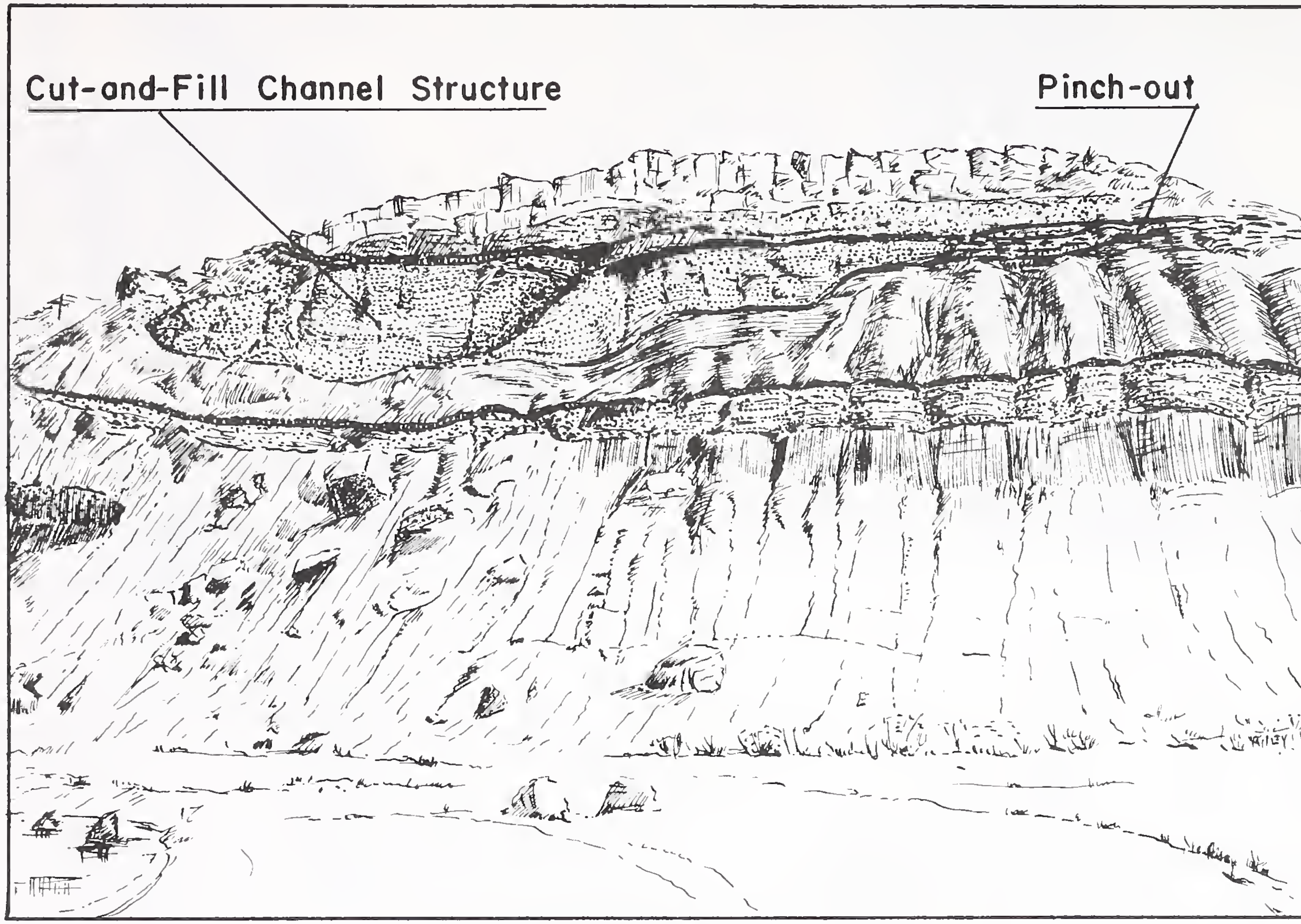
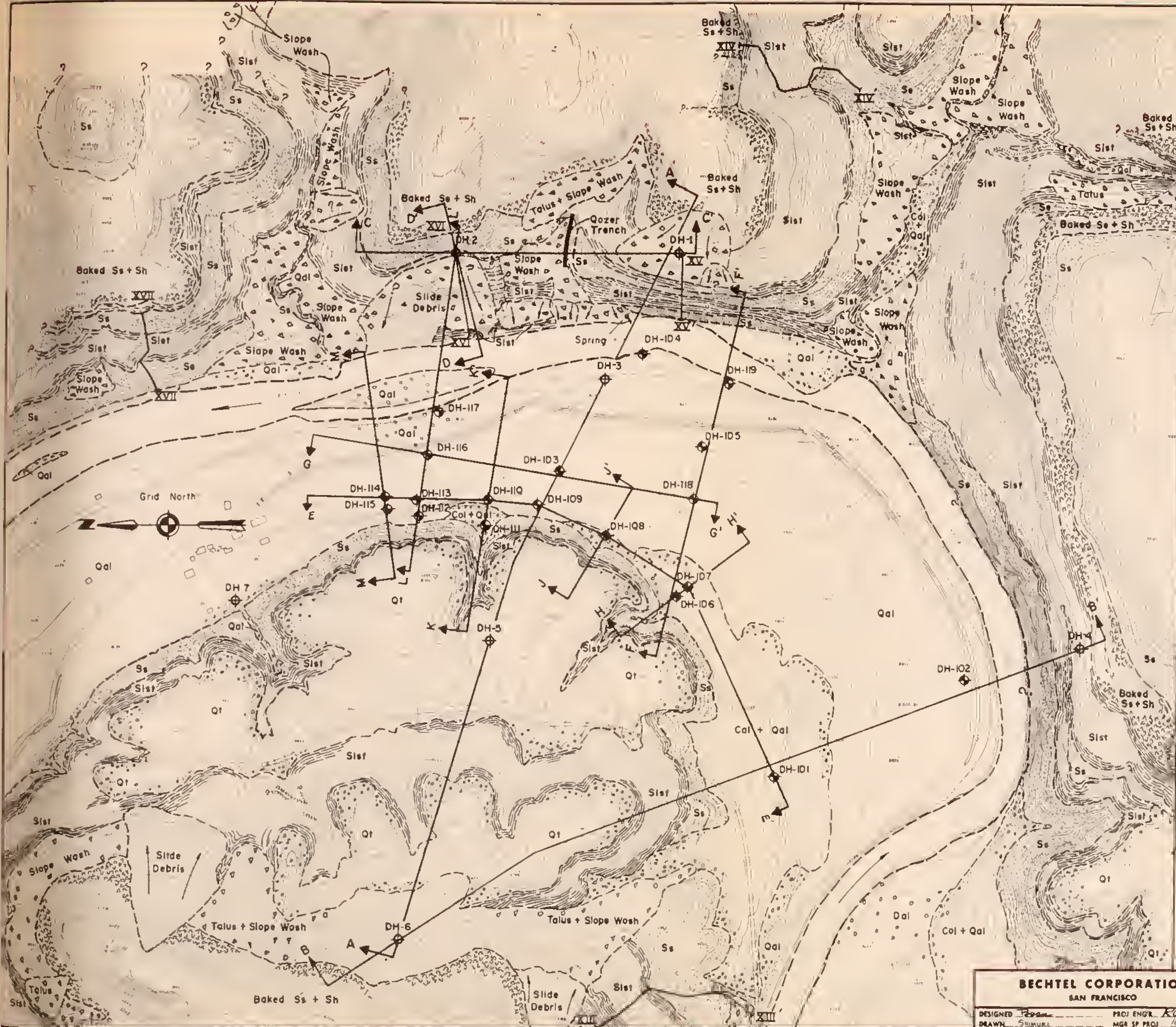


FIGURE V-1

Exposure on Tongue River of the Tongue River Member (Fort Union Formation) showing lenticular sandstone beds (indicated by dots). Note cut-and-fill channel structure in sandstone bed and abrupt pinch-out on right side. Thin coal beds (black) mark undulating contact between sandstone and siltstone. This 120 foot cliff illustrates interbedded, lenticular conditions found in drill holes at High Tongue River Dam.



EXPLANATION

QUATERNARY

- **Talus + Slope Wash.** Silt, sand, gravel and boulders derived from weathering and breakdown of steep slopes
- **Qal:** Alluvium silt, sand and gravel in river bottom and lowlands
- **Col + Qal:** Colluvium + Alluvium: locally derived slope wash merging with alluvium
- **Qt:** River terrace deposits silt, sand and gravel; characterized by well rounded predominantly sedimentary gravel and distinctive igneous gravel

EOCENE — FORT UNION FORMATION — Tongue River Member

- **Baked Ss + Sh:** Locally referred to as "clinker" and "scoria", red baked sandstone and shale, platy to closely broken and jointed; some vesicular "scoria" has distinctive red brick color; extremely permeable.
- **Slst:** Siltstone gray laminated to massive: commonly closely broken and jointed; yellow staining and occasional gypsum filling in joints, some clayey beds; ravels when weathered. contains coal beds and some carbonaceous siltstone beds.
- **Coal:** Black crumbly; includes earthy coal and other prominent carbonaceous beds, coal beds range from <1D' to > 4' in thickness
- **Ss:** Sandstone; buff to gray very fine-to medium-grained with some coarse-grained sequences; weakly to moderately well cemented strata; massive to thinly bedded with occasional cross bedded sequences relatively free of joints and fractures; contains little to no coal.

SYMBOLS

- A — A′ Line of Geologic Section
- V — V′ Line of Measured Stratigraphic Section
- 1967 Drill Hole
- 1968 Drill Hole (IDQ Number Series)
- Geologic contact; dashed where inferred; queried where doubtful

Geology mapped July 1967

REFERENCE DRAWINGS
1. Stratigraphic sections shown on Dwg no 6694-V-DD9
2. Geologic sections shown on Dwg no. 6694-V-DD8

Topographic Map
by
R. M. TOWILL CORP
Date of photography June 26, 1967

SCALE 200 0 200 400 Feet
Contour Interval 5 Feet

NO	DATE	REVISIONS	BY	CK	PROJ ENGR	MGR SP PROJ	MGR ENGR

HIGH TONGUE RIVER DAM SITE
GEOLOGIC MAP

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

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SAN FRANCISCO

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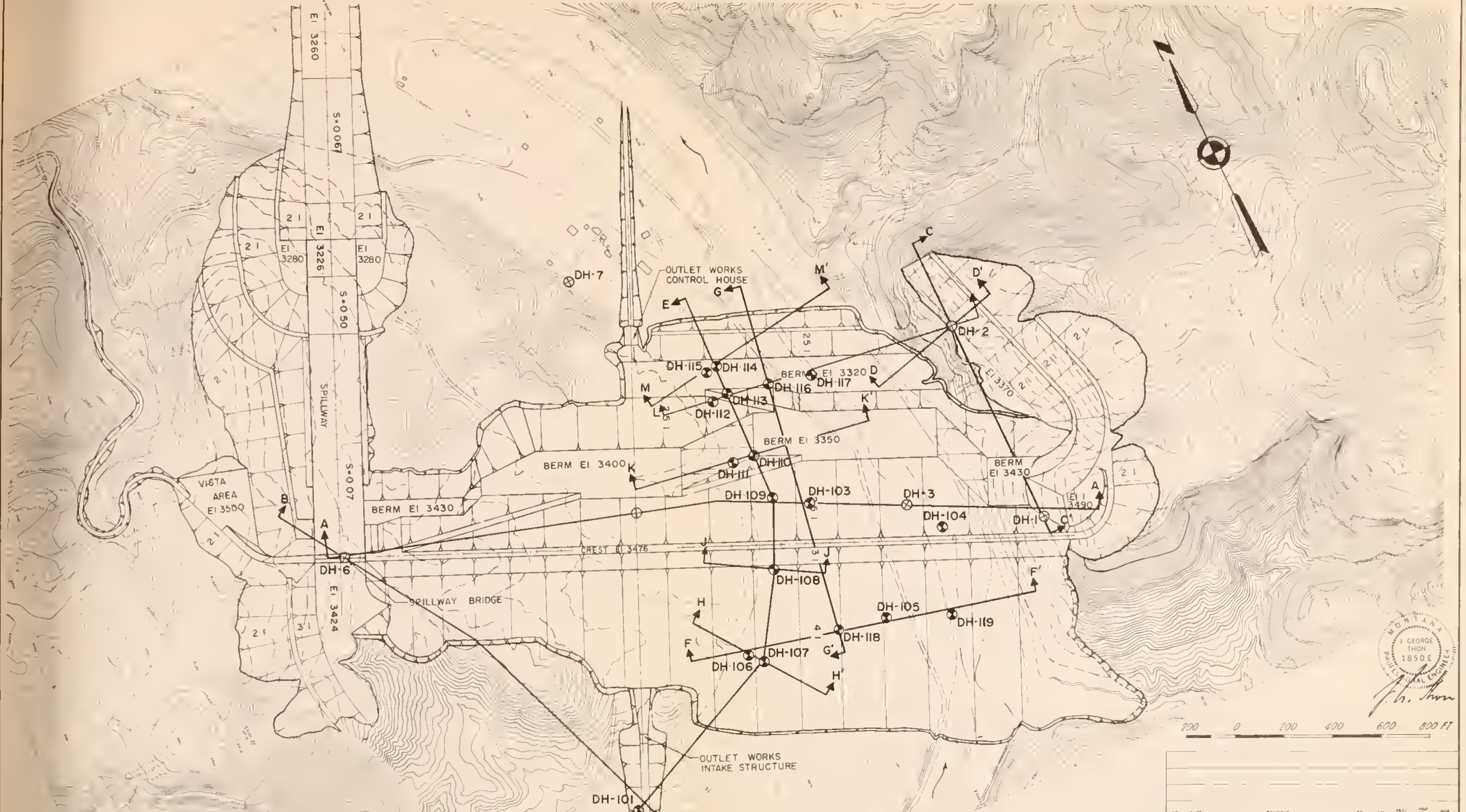
DRAWN ___ MGR SP PROJ ___
CHECKED ___ MGR ENGR ___

APPROVED ___ DATE ___

JOB No	DRAWING No	REV
6694	6694-V-007	



HIGH TONGUE RIVER DAM SITE
LOCATION OF DRILL HOLES AND SECTIONS

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

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MGR ENGR
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DATE
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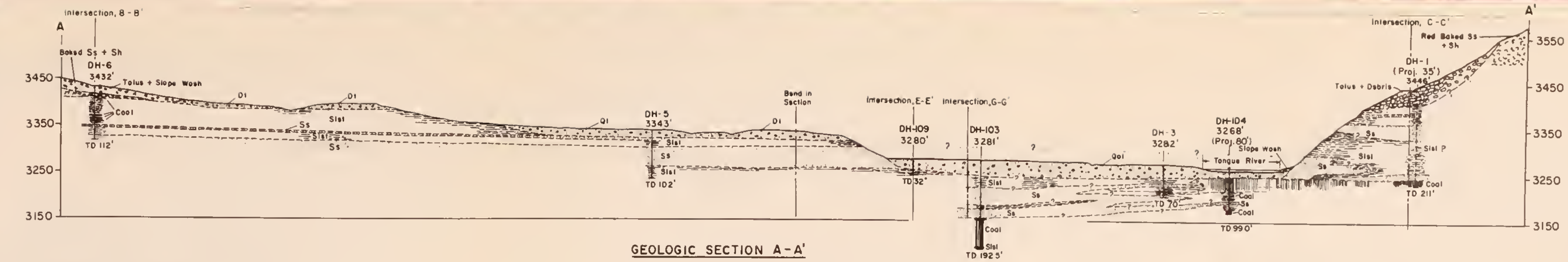
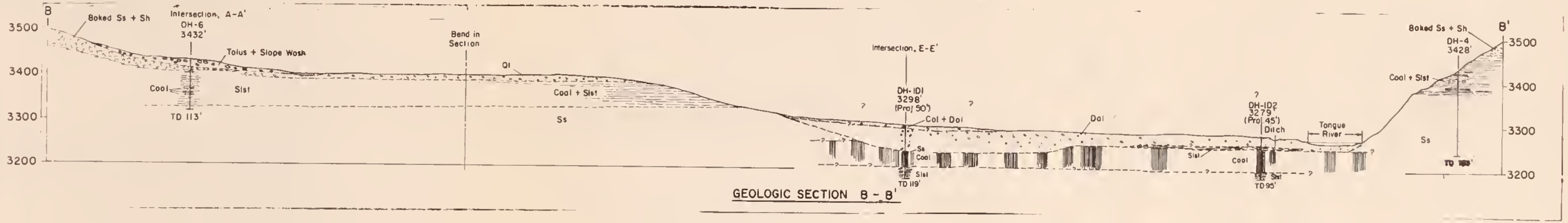
DRAWING No 6694-V-007A



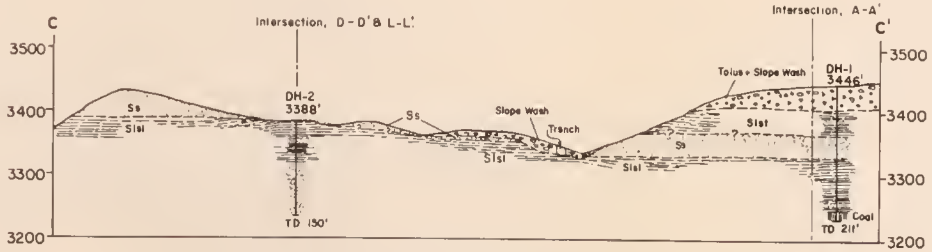
GEOLOGIC SECTION A-A'



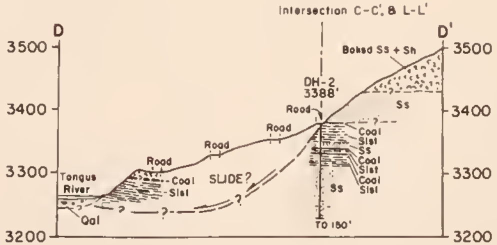
GEOLOGIC SECTION B - B'

REFERENCE DRAWING:

1. For location of geologic sections see Dwg. no. 6694-V-007
2. For explanation of abbreviations see Dwg. no. 6694-V-007



GEOLOGIC SECTION C - C'



GEOLOGIC SECTION D-D'

100 0 100 300 Feet
VERT & HORIZ SCALE

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HIGH TONGUE RIVER DAM SITE
GEOLOGIC SECTIONS
SHEET 1 OF 2

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

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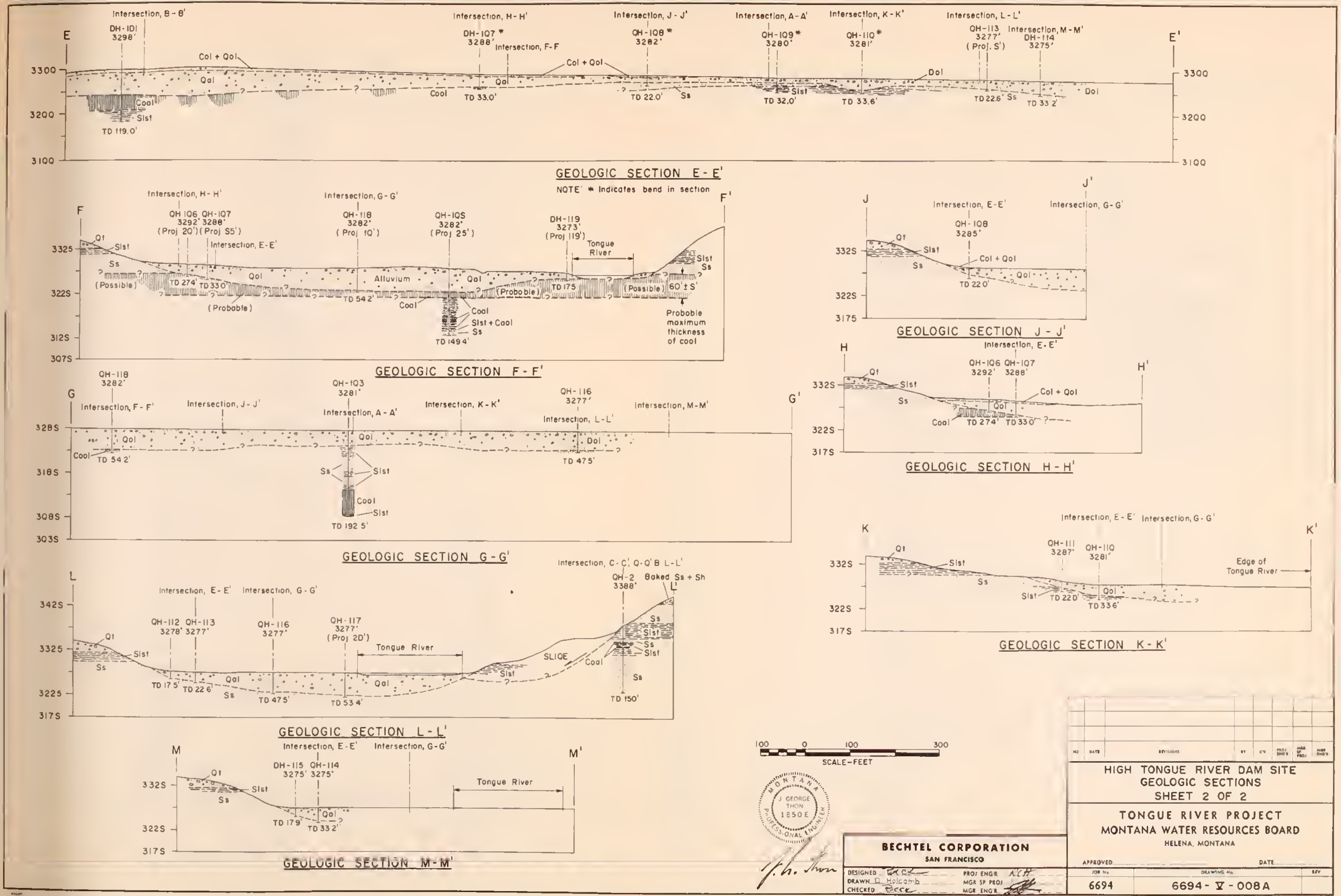
DESIGNED Beck — PROJ ENGR
DRAWN D.L. HOLCOMB — MGR SP PROJ
CHECKED Beck — MGR ENGR

APPROVED — DATE

JOB No.	DRAWING No.
6694	6694-V-008



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HIGH TONGUE RIVER DAM SITE
GEOLOGIC SECTIONS
SHEET 2 OF 2

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
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DRAWN D. Holcomb MGR SP PROJ ______
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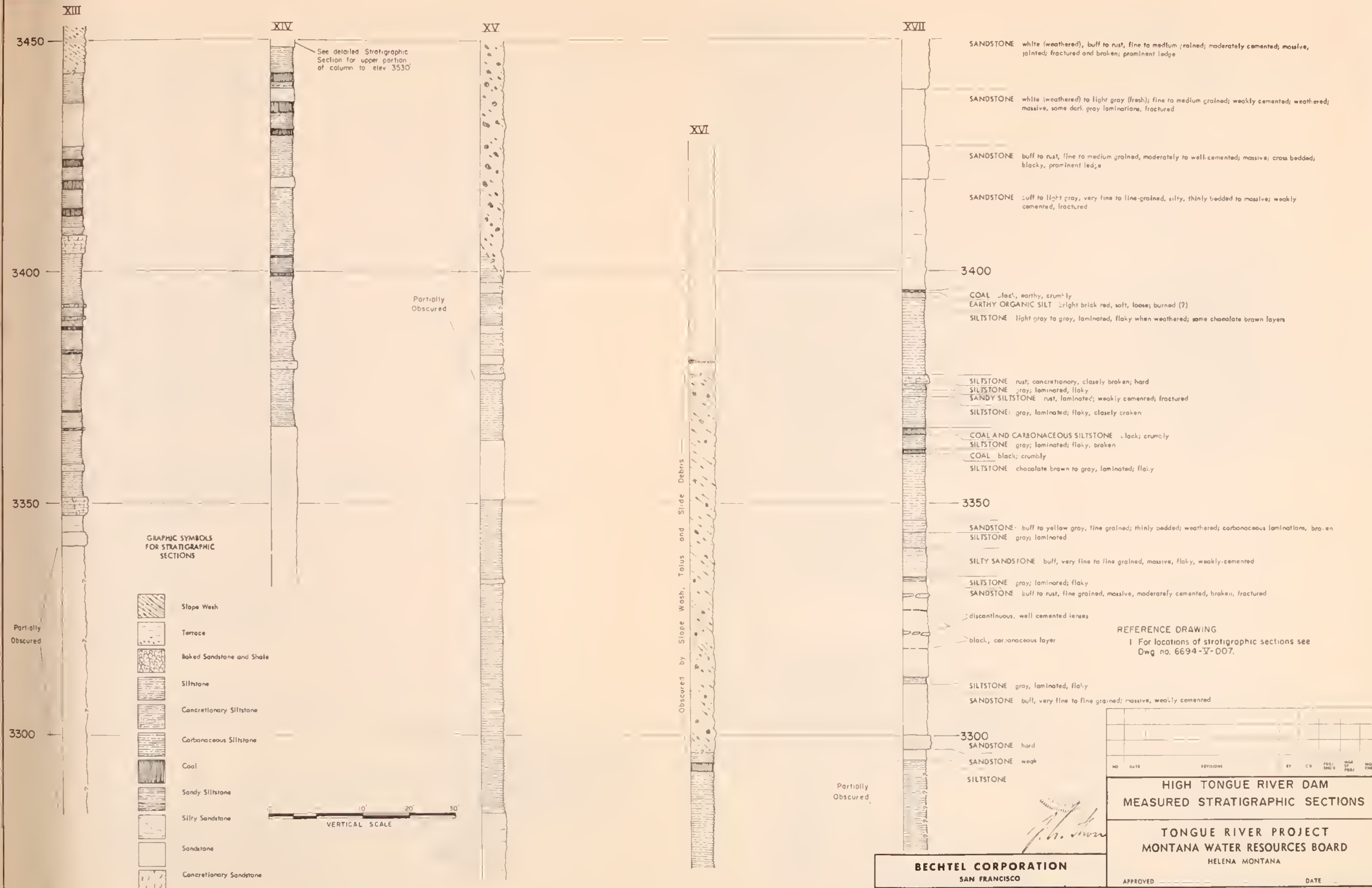
6694	6694 - V - 008A	



REFERENCE DRAWING

1 For locations of stratigraphic sections see Dwg no. 6694-V-007.

NO	DATE	REVISIONS	BY	CK	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
MEASURED STRATIGRAPHIC SECTIONS

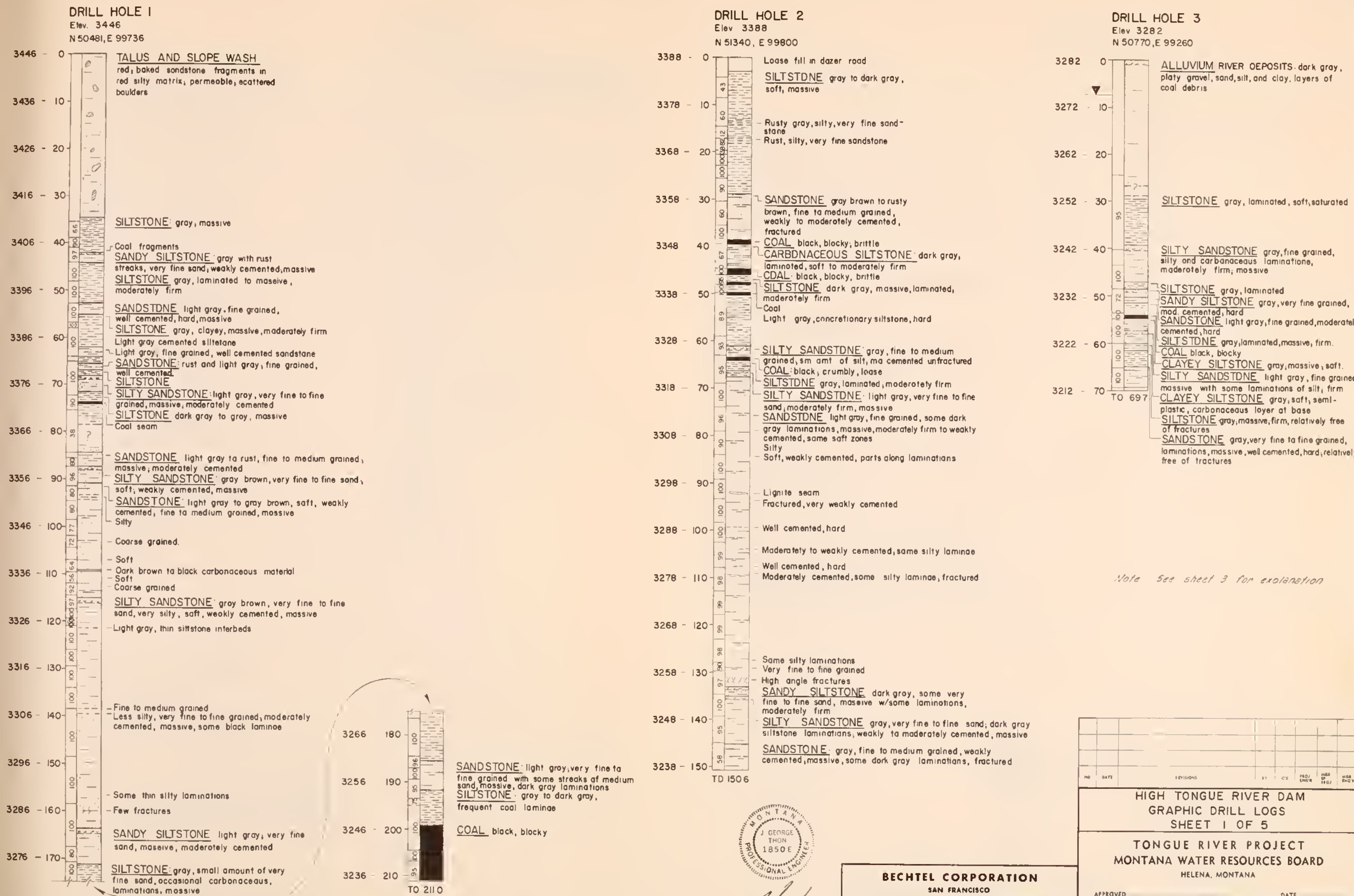
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA MONTANA

APPROVED ______ DATE ______

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED Bow
DRAWN Bow
CHECKED Bow
PROJ ENG'R RCH
MGR SP PROJ
MGR ENG'R

JOB No.	DRAWING No.	REV
6694	6694-V-009	



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SAN FRANCISCO

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DRAWN ___ MGR SP PROJ ___
CHECKED BOCK MGR ENG'R ___

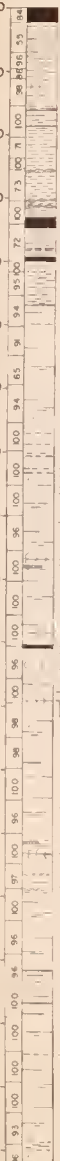
HIGH TONGUE RIVER DAM
GRAPHIC DRILL LOGS
SHEET 1 OF 5

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED ___ DATE ___

JOB No.	DRAWING No.	REV
6694	6694 - V - 012	

DRILL HOLE 4
Elev 3428
N 48935, E 98206

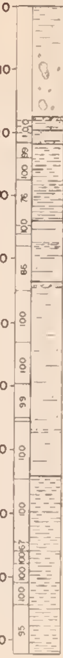


Depth scale (elevation – depth): 3428 - 0; 3418 - 10; 3408 - 20; 3398 - 30; 3388 - 40; 3378 - 50; 3368 - 60; 3358 - 70; 3348 - 80; 3338 - 90; 3328 - 100; 3318 - 110; 3308 - 120; 3298 - 130; 3288 - 140; 3278 - 150; 3268 - 160; 3258 - 170; 3248 - 180

- COAL black, crumbly, two other minor coal beds in cut bank above top of hole
- SILTSTONE light gray to gray, laminated to massive, parts on horizontal surface, some buff sandy siltstone layers
- Soft seam.
- Buff sandy siltstone, fractured
- SANDSTONE light gray, fine to med grained, well cemented, massive
- Rust
- Gray
- Concretionary rust siltstone
- Gray
- Rust concretionary siltstone
- Rust concretionary siltstone
- COAL black, crumbly
- Layer of rust sandstone
- Coal
- Some very fine sand
- SANDSTONE light gray, very fine to fine sand, silty, weakly to moderately cemented, massive, unfractured
- Well cemented
- Silty streaks
- Well cemented, fractured
- Weakly cemented
- Light brown to buff
- Soft, very weakly cemented, fractured
- Light gray brown, soft, fractured
- Fractured
- Carbonaceous laminations
- Soft, very weak, medium grained
- Soft zone
- Medium-to coarse-grained
- Light gray
- Medium-grained
- Gray brown
- Coal seam
- Medium-grained
- Fractured
- Coarse grained
- Medium-to coarse-grained
- Fractured
- Gray, coarse grained, massive
- Black carbonaceous laminations
- Black carbonaceous laminations
- Black carbonaceous siltstone
- Fractured
- Soft
- Streaks of gray siltstone
- Siltstone layer
- Brown, coarse grained with light gray fine-grained, well cemented interbeds
- SILTY SANDSTONE gray, fine-grained, some siltstone laminations, mod cemented, massive
- SANDSTONE light gray, fine-to medium-grained, moderately cemented, some dark gray laminations, massive
- Well cemented, hard
- Layer of silty sandstone
- Medium grained, weakly to moderately cemented

TO 183.5

DRILL HOLE 5
Elev 3343
N 51240, E 98240



Depth scale (elevation – depth): 3343 - 0; 3333 - 10; 3323 - 20; 3313 - 30; 3303 - 40; 3293 - 50; 3283 - 60; 3273 - 70; 3263 - 80; 3253 - 90; 3243 - 100

- TERRACE DEPOSITS upper portion fine to medium sand with small amt of silt-clay, permeable, some caliche, bottom portion, clean fine to medium sand with well graded platy to subround sedimentary gravel, scattered cobbles and boulders, some igneous material buff to rust and reddish brown
- SILTY SANDSTONE buff, very fine to fine sand
- SANDY SILTSTONE buff to light gray, very fine sand, massive with some lamination, firm
- SILTSTONE gray, some very fine sand, massive with some laminations, firm
- SANDSTONE lt. gray to gray, very fine to fine-grained, black laminations, massive, moderately cemented
- Well cemented
- Silty, buff to brown, soft
- SILTY SANDSTONE gray brown, weakly cemented to soft, very fine-to fine-grained
- Soft, parts along horizontal bedding
- Blue gray, soft, silty
- Thin bed of buff sandstone
- Firmer, less silty
- Layer of carbonaceous material
- Layer of sandy siltstone
- Carbonaceous layer
- Gray, black laminations, mod cemented, some silty, yellow blebs
- SILTSTONE gray, massive, clayey
- Some thin sandy layers

TO 102.2

DRILL HOLE 6
Elev 3432
N 51563, E 97080

Depth scale (elevation – depth): 3432 - 0; 3422 - 10; 3412 - 20; 3402 - 30; 3392 - 40; 3382 - 50; 3372 - 60; 3362 - 70; 3352 - 80; 3342 - 90; 3332 - 100; 3322 - 110

- TALUS AND SLOPE WASH soil, rock debris
- SANDSTONE AND SHALE red and reddish brown, closely broken, baked rock, Talus-not in place
- SILTSTONE gray, massive, clayey
- COAL black, crumbly
- SILTSTONE dark gray, clayey, massive to laminated, firm, unfractured
- Black carbonaceous material, soft
- SANDSTONE lt gray to gray, v f-to fine-grained, well cemented, massive, hard, fract - some fractures cemented
- Layer of sandy siltstone
- Cemented sandy siltstone
- Fine to medium sandstone
- Layer of cemented, fine sandstone, fractured
- Coal
- Concretionary siltstone
- COAL black, blocky, fractured
- Some sandy laminae
- COAL black, crumbly
- COAL AND CARBONACEOUS SILTSTONE
- SILTSTONE
- SANDSTONE lt gray, very fine-grained, well cemented, hard, massive
- SILTSTONE
- Well cemented siltstone
- Well cemented siltstone
- SILTY SANDSTONE light gray, very fine to fine, silty, well cemented
- SILTSTONE
- SILTY SANDSTONE lt gray, very fine, hard, fractured
- SANDSTONE gray, very fine to fine, massive
- SILTSTONE gray, laminated
- SANDSTONE lt gray, very fine, massive, well cemented
- SILTY SANDSTONE lt gray, v f to fine, black laminations, moderately cemented, massive
- SANDSTONE lt gray, fine to medium, black laminations, mod cemented

TO 112.8

DRILL HOLE 7
Elev 3278
N 52175, E 98420

Depth scale (elevation – depth): 3278 - 0; 3268 - 10; 3258 - 20; 3248 - 30; 3238 - 40

- ALLUVIUM silt, sand, and gravel
- SANDSTONE light gray, fine-to medium-grained, small amount of silt, weakly cemented, massive, few fractures
- Fracture zone
- Carbonaceous laminations

TO 39.9

Note See sheet 3 for explanat...

MONTANA
J. GEORGE THON
1850 E
PROFESSIONAL ENGINEER

NO	DATE	REVISIONS	BY	CK	PROJ ENG'R	MGR SF PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
GRAPHIC DRILL LOGS
SHEET 2 OF 5

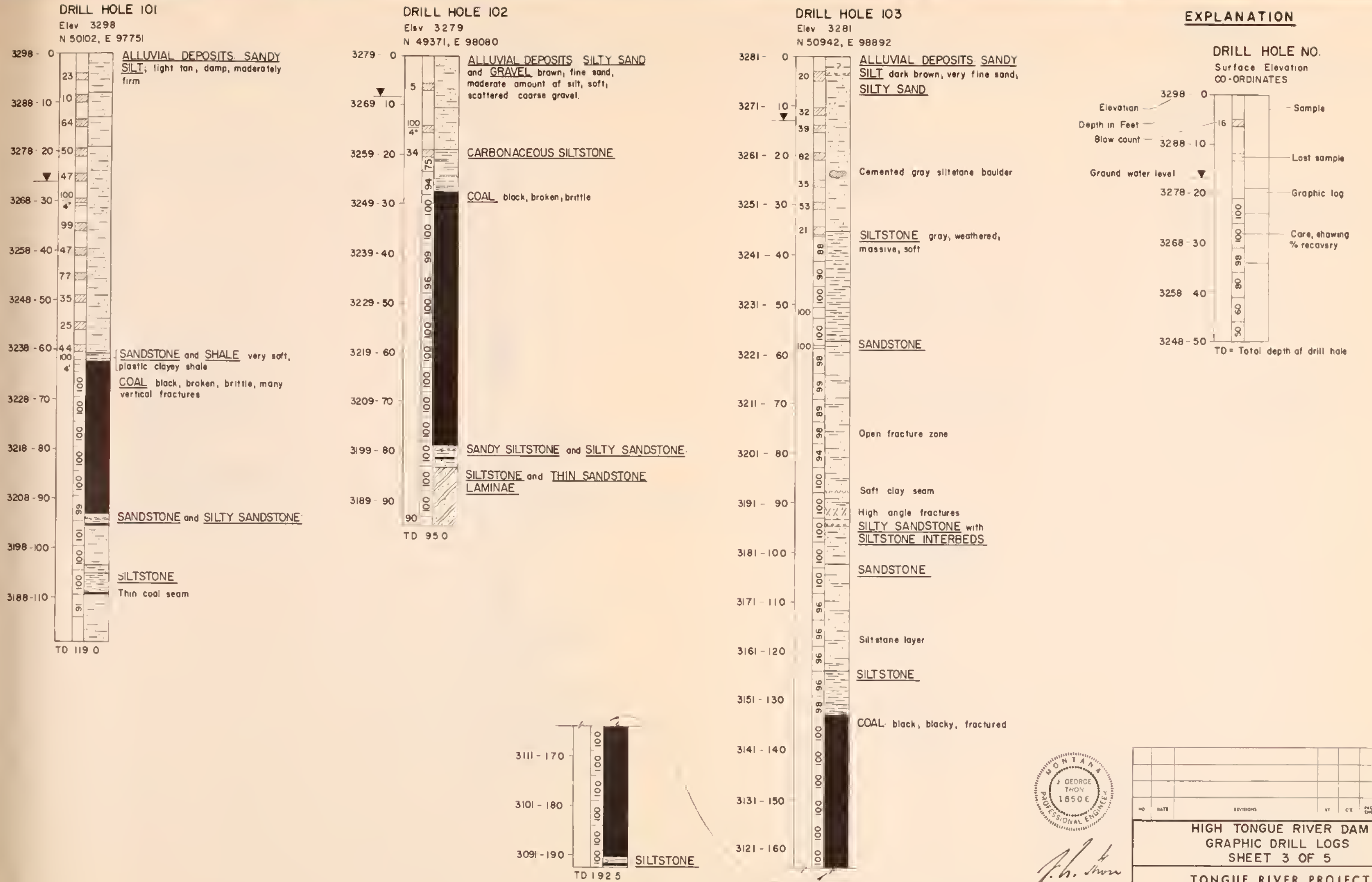
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED		PROJ ENG'R	RCH
DRAWN		MGR SF PROJ	
CHECKED	BOCK	MGR ENG'R	

APPROVED — DATE

JOB No.	DRAWING No.	REV
6694	6694 - V - 013	



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1850 E
PROFESSIONAL ENGINEER

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HIGH TONGUE RIVER DAM
GRAPHIC DRILL LOGS
SHEET 3 OF 5

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
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DRAWN H. Mitchell MGR SP PROJ
CHECKED ___ MGR ENGR

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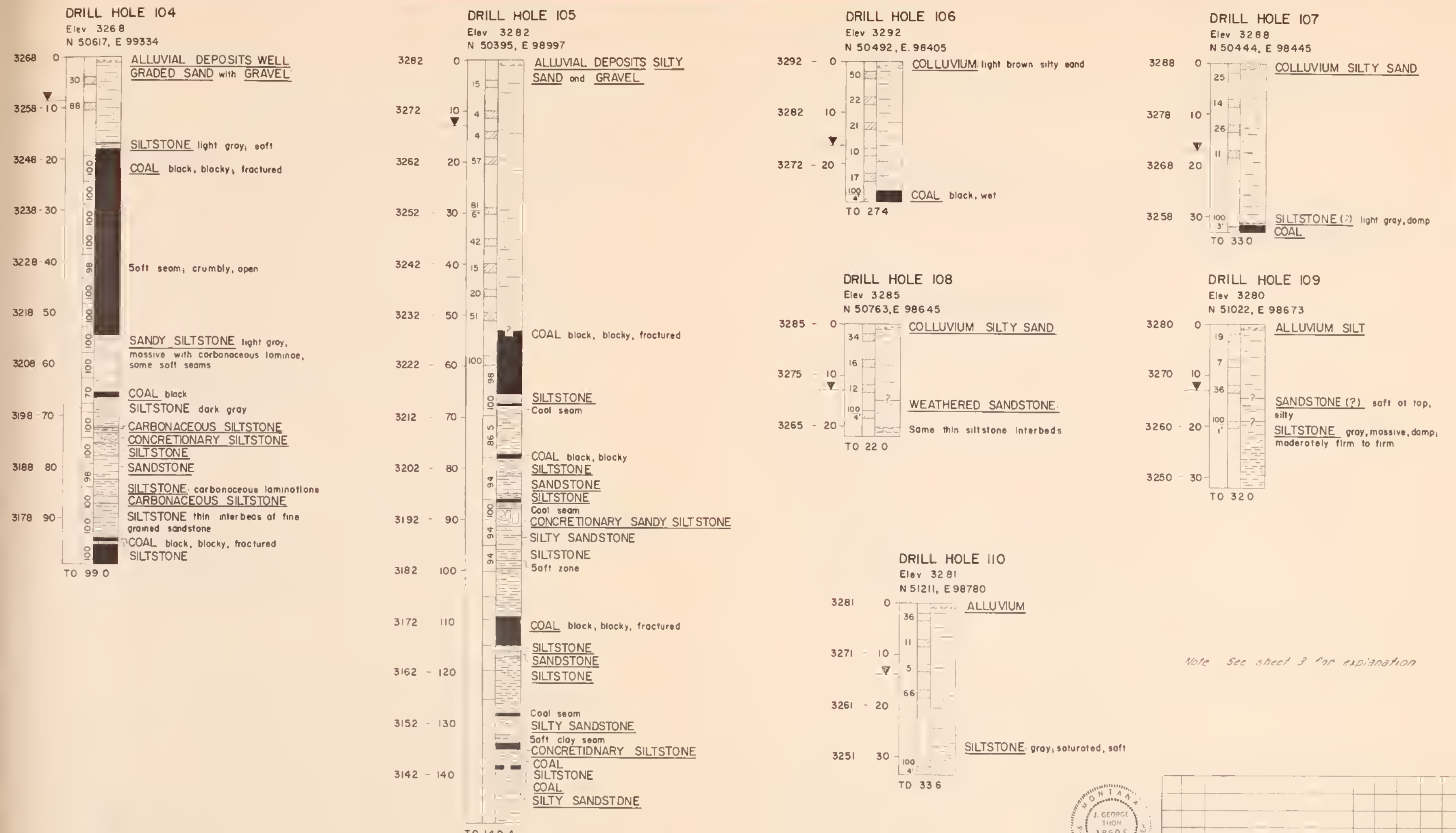
6694	6694 - V - 014	



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HIGH TONGUE RIVER DAM
GRAPHIC DRILL LOGS
SHEET 4 OF 5

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

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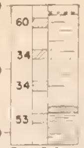
CHECKED		MGR ENGR	

APPROVED		DATE
JOB No.	DRAWING No.	REV
6694	6694 - V - 015	

DRILL HOLE 111
Elev 3287
N 51225, E 98698

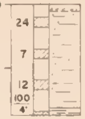


COLLUVIUM SILTY SAND

Rock
WEATHERED SILTSTONE gray; massive; fractured, damp, firm

TD 22 0

DRILL HOLE 112
Elev 3279
N 51485, E 98729

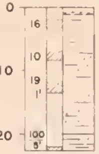


ALLUVIUM

SILTY SANDSTONE blue - gray, fine sand, laminated, wet, very firm

TD 17 5

DRILL HOLE 113
Elev 3277
N 51492, E 98787

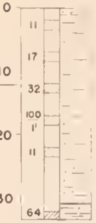


ALLUVIUM SILT

SANDSTONE gray, weathered, soft

TD 22 6

DRILL HOLE 114
Elev 3275
N 51610, E 98797

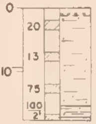


ALLUVIUM

SANDSTONE gray, medium grained; wet; weathered.

TD 33 2

DRILL HOLE 115
Elev 3275
N 51600, E 98749

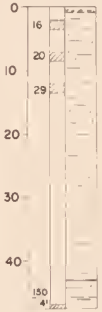


ALLUVIUM

SANDSTONE gray; medium sand, weathered, saturated; moderately hard

TD 17.9

DRILL HOLE 116
Elev 3277
N 51451, E 98957

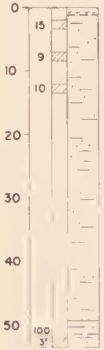


ALLUVIUM SILTY FINE SAND

SANDSTONE gray, weathered; saturated, medium-grained, soft to hard

TD 47 5

DRILL HOLE 117
Elev 3277
N 51412, E 99114



ALLUVIUM SILT, SILTY SAND and GRAVEL

SANDSTONE gray, fine- to medium-grained, laminate of coal, moderately firm to hard

TD 53 4

DRILL HOLE 118
Elev 3282
N 50425, E 98774

ALLUVIAL DEPOSITS SILTY SAND, SAND and GRAVEL

COAL black

TD 54 2

DRILL HOLE 119
Elev 3273
N 50286, E 99215

ALLUVIUM

COAL black

TD 17 5

Note See sheet 5 for explanation

MONTANA J. GEORGE THON 1850 E PROFESSIONAL ENGINEER

NO	DATE	REVISIONS	BY	CK	PROJ ENGR	MGR SP PROJ	MGR ENGR

HIGH TONGUE RIVER DAM
GRAPHIC DRILL LOGS
SHEET 5 OF 5

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED DATE

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED Beck — PROJ ENGR
DRAWN — MGR SP PROJ
CHECKED Beck — MGR ENGR

JOB No	DRAWING No	REV
6694	6694 - V - 016	

VI. CONSTRUCTION MATERIALS

BORROW AREA EXPLORATIONS

The borrow area investigation was conducted between July 10, 1967 and September 16, 1967. The investigation consisted of excavating pits with a backhoe to depths up to 13 feet or until water conditions or bedrock made digging impractical. The average pit depth was approximately 11 feet and the sides of the pits were logged and sampled. Bags of soil representing the different classifications were taken from the sides of the pits and the pits backfilled. The borrow investigation was conducted for two locations; the existing Tongue River Dam and the Four Mile Damsite. Detailed descriptions of these explorations are described for each site in the following sections.

TONGUE RIVER DAM

Explorations for borrow materials were conducted in the valley along Leaf Rock Creek, on the Left Abutment and in Borrow Areas A, B, C and E. Photo-contour maps of these borrow areas as well as the logs and soil test data are presented in the Supporting Data.

The Leaf Rock Creek borrow area is approximately 8000 feet long by 600 feet wide and composed of an alluvial filled valley overlain by fine-grained material. A total of 8 backhoe pits were dug in this area, and the logs are shown on Drawing No. 6694-VI-009. The fine-grained materials are clays and silts mixed with fine-grained sands usually being of low plasticity and with layers of clean sands and gravels scattered throughout. Generally this finer material appears to be at least 12 to 13 feet deep in the lower portion of the valley. In the upper 2000 feet of the valley, the fine-grained material decreases in thickness to only about a foot.

The left abutment and Borrow Areas A and B contain gravelly materials. The logs of pits from these areas are shown on Drawing No. 6694-VI-010. At the left abutment there are 8 to 10 feet of gravel above the bedrock but the area is small and represents only a small quantity. Borrow Areas A and B are relatively small and the water table is near the surface. The area consists of sandy gravel of unknown depth covered with 3 to 7 feet of silts and silty sands. Because the gravel would have to be removed from below the water table and the apparent small quantity, these areas were not considered to be of great importance other than perhaps for filter or aggregate production.

Borrow Area C is a generally level field adjacent to the river. Three pits in this area indicate silty and clayey sandy gravels overlain in some parts by 4 to 5 feet of silty clay (logs are shown on Drawing No. 6694-VI-011.) The clayey material is of small quantity. Gravelly material would require processing to be used as filter, drain or aggregate material.

Borrow Area E is divided into a lower flat portion and a terraced portion. Four pits in the flat portion indicated 8 to 11 feet of clayey, silty, sandy soil averaging approximately 9 feet in depth. (See logs on Drawing No. 6694-VI-011). Pits in the terraces indicated sandy gravel with some fines.

HIGH TONGUE RIVER DAMSITE

Borrow Areas G, H, I, K, L, M, N, P, R and two far removed areas, D and Post Creek, were all investigated as sources of material for the High Tongue River damsite. Quantities of materials and their distance from the damsite are shown on Table VI-1. Borrow area maps and logs are presented in the Supporting Data.

Borrow Area R is a large field with a low level portion and a terraced portion. A total of 10 pits were dug and the logs are shown on Drawing No. 6694-VI-018. The level portion is composed of clay and silt and silty sand overlying clean sand and gravel. The fine-grained material is of medium to low plasticity and stratified with thin sand and gravel layers and ranges in depth from 4 feet to 12 feet and averages 10 feet deep. The terraces are composed of fairly clean sandy gravel and should average 8 feet deep. This sandy gravel would require some processing but is generally cleaner than in other areas.

Borrow Area P is in the dam foundation area and also has a low level portion and a terraced portion. Drawing No. 6694-VI-017 shows the logs from this area. In general, the level area is silty sand and silty gravel overlain by 2 to 5 feet of sandy silt. The terraced portion contains silty sandy gravel and extends to depths up to 12 feet or greater on the tops of the terraces and averages about eight feet. Processing would be required to produce filter, drain or aggregate materials.

Borrow Areas M and N are two generally level fields adjacent to the river. Two pits were dug in each field and their logs appear on Drawing No. 6694-VI-016. M is composed of approximately 8 feet of sandy slightly clayey silt overlying sand and gravel with the silt stratified with thin sand and gravel layers. N is composed of approximately 10 feet of silty gravelly sand generally stratified.

Borrow Area L is a large level field which lies between the toe of the slope and the river. Eight pits were excavated in this area and their logs are shown on Drawing No. 6694-VI-015. The area is composed primarily of clays, silts and silty sands. The clayey material nearer the toe of the slope is 11 to 12 feet in depth and overlying sands and sandy gravel. The soil near the river tends to be sandier and 5 to 10 feet deep above the sandy gravel. However, the fine-grained material should average at least 9 feet in depth.

Borrow Area K is a small level field. Drawing No. 6694-VI-013 shows the logs of 4 pits excavated in this area. The material consists of sand and sandy gravel overlain by clays, silts and silty sands. The fine-grained soils range from 4 feet to 12 feet and should average 10 feet deep.

TABLE VI-1

SUMMARY OF BORROW AREA QUANTITIES

Borrow Area	Distance Miles	Stripping Depth Ft.	Stripping Volume 1000 CY	Impervious Depth Ft.	Impervious Volume 1000 CY	Impervious Cum Volume 1000 CY	Sand and Gravel Depth Ft.	Sand and Gravel Volume 1000 CY	Sand and Gravel Cum Volume 1000 CY	Fill Materia Total Cum Volume 1000 CY
FOUR MILE CREEK DAM										
P Upper Terrace	0	1	44				8	345	345	345
P Lower Flat	0	1	66	2	130	130	7	457	802	932
R Upper Terrace	.5	1	56				8	445	1,247	1,377
R Lower Flat	.7	1	145	10	1,449	1,579				2,826
N	.9	1	59				10	577	1,824	3,403
M	1.2	1	34	8	266	1,845				3,669
L	1.9	1	166	9	1,490	3,335				5,159
K	2.8	1	89	10	885	4,220				6,044
H	3.2	1	91				8	725	2,549	6,769
G Upper Terrace	4.0	3	214				7	491	3,040	7,260
G Lower Flat	4.3	1	60	4	240	4,460	4	240	3,280	7,740
I	4.7	1	199	5	991	5,451				8,731
Post Creek	5.5	1	71				8	568	3,848	9,299
D	5.9	1								

Borrow Area H is made up of an alluvial fan portion and a terrace portion. Drawing No. 6694-VI-013 shows the logs of 6 pits in this area. The material is mostly sand and gravel with fines which would require that the gravel be processed for use as filter, drain or aggregate. The gravelly material ranges in depth from 6 feet to 13 feet and should average 8 feet deep.

Borrow Area G is made up of a low generally level portion and a terraced portion. Five pits were dug in the lower portion and four pits were dug in the terraced portion. Their logs are shown on Drawing No. 6694-VI-012. The terraced portion consists of sandy gravel overlain by 2 to 6 feet of silty clay and clayey silt. There should average 7 feet of sand and gravel. The lower portion is composed of sand and gravel overlain by 4 to 9 feet of silty clay and clayey silt. There should be approximately 4 feet of fine-grained material and 4 feet of sand and gravel from this area.

Borrow Area I is generally a level hay field. Eight pits were located in this area and logs are shown on Drawing No. 6694-VI-014. This area consists of clean sand and sandy gravel overlain by silts, clayey silts and silty sands. The fine-grained material varies in thickness from about 3 feet to about 8 feet averaging approximately 5 feet. Sand and gravel obtained from this area would have to be removed from below the water table and would require processing for use as filter, drain or aggregate. The quantity of gravelly material is not known.

Borrow Areas D and Post Creek are two areas farthest from the damsite. Two pits were put into each area and their logs are shown on Drawing No. 6694-VI-019. Post Creek is a long narrow very rocky valley. The logs indicated sandy gravel with some boulders and the depth of the material may average 8 feet deep. Because of the location of D the limits of the area were not defined. The logs of the two pits indicate 5 to 8 feet of sandy silt or fine-grained silty sand.

CONCRETE AGGREGATES

The most feasible local source of concrete aggregates would be located on the upper terraces. While these areas were not specifically investigated for concrete aggregates the grain size distribution curves are available from the borrow area explorations. It is not known at this time as to whether these upper terrace deposits would meet acceptable concrete aggregate tests. The gravel deposits lying along the present streambed contain an appreciable amount of sedimentary and softer rocks and are therefore less likely to be acceptable.

The nearest known commercial sources of concrete aggregates are located at Sheridan, Wyoming where three firms are producing acceptable materials. The aggregate deposits are all located on the upper terraces west of town and are from a similar geologic period to those found along the Tongue River.

The concrete aggregate used in the present dam came from a pit located a few miles upstream of the dam. Nothing is known regarding the aggregate plant, the resulting product or the type of cement used.

RIPRAP

No known sources of good, hard, sound rock are located along the Tongue River. A fairly firm cemented sandstone rib was visually examined and rejected for being too soft for long life. A small possibly useful sandstone layer is present near the High Tongue River damsite as described in the Geological Summary. Baked sandstone and shale, locally known as clinker, while frequently used for road surfacing would produce very little material larger than six inch size. Nearest possible source of an igneous rock that might be suitable for riprap is located in the Big Horn Mountains approximately 40 miles to the southwest. The lack of good riprap was recognized during the construction of the existing dam and thickness was increased from 30 inches to 15 feet measured normal to the slope with the material being the above-mentioned baked shale. The present condition of the upstream face appears to be satisfactory.

Exposures of baked shale occur at or slightly above the present reservoir while at the Four Mile Dam Site the baked shales are located along the tops of higher ridges generally above any proposed dam.

TESTING

Representative samples of all materials encountered in the explorations were sent to Northern Testing Laboratories at Billings, Montana, for classification tests. Complete test data is presented in the Supporting Data, Part VI.

Samples of materials found to be representative of material types and areas were sent to Geo-Testing, Inc., San Rafael, California, for more complete testing, including shear, consolidation, compaction and permeability tests. Complete test data on the comprehensive testing and summary of all the testing performed is included in the Supporting Data, Part VI.

The soil properties adopted for design are presented in Part VII, Embankment - Stability Analysis.

VII. EMBANKMENT

GENERAL

The dam embankment is designed for economical raising from Stage 1, to Stage II as shown on Dwgs. No. 6694-VII-007 and 008. Studies of economical dam heightand spillway combinations, considering the two-stage construction requirements, indicated that a spillway width of about 200 feet would be preferable. The Stage I spillway crest will be at El. 3438 with dam crest at 3464, providing some two feet of freeboard above the probable maximum flood water surface. The Stage II spillway crest will be at El. 3453 with a dam crest at 3476, again providing 2 feet of flood freeboard.

The spillway bridge beams had to have adequate clearance from the spillway upper nappe water surface profile. The first stage bridge had to be located nearly in the same position downstream and above the spillway crest as it is for the second stage. Therefore, the spillway crest walls are full height to support the bridge in the Stage II position. The Stage I dam embankment is also set at the Stage II crest El. 3476 adjacent to the spillway to provide access over the bridge.

DAM ALIGNMENT

The placement of the dam was developed to take advantage of the most favorable foundation configuration and geologic conditions on the site.

A possible axis was investigated some 2000 feet upstream. The left abutment at that location is steeper and contains more baked rock and the spillway alignment would have been longer and required more excavation. However, the primary reason for rejecting an upstream axis, such as along the geologic section B-B shown on Dwg. No. 6694-V-007A, is the almost continuous thick coal bed encountered in borings along that location.

A shift of the dam alignment downstream would have moved the maximum section of the dam into a slide area mapped on the right abutment (Section D-D, Dwg. No. 6694-V-007A). Again, the spillway alignment would have been longer and substantially greater excavation would have been required.

Along the selected alignment, shown on Dwg. No. 6694-VII-001, the Zone 1 impervious core has good contact with the abutments. Right abutment contours converge downstream. On the left abutment the Zone 1 core contact is well keyed into an existing draw.

DAM SECTION

The dam embankment section has been designed to:

1. provide adequate safety against low foundation shear strength,

2. provide seepage control within the embankment,

3. provide partial seepage control for pervious foundation layers,

4. provide for economical use of available earth construction materials.

The embankment has been designed with relatively flat slopes: Four horizontal to one vertical on the upstream slope and $2\frac{1}{2}$ horizontal to one vertical with a series of wide berms on the downstream slope.

These embankment proportions were necessary to reduce shear stresses on lenses of weak clay shale in the foundation. A full description of the studies used to guide the proportioning of the embankment slopes and berms are presented in the section "Stability Analysis".

In order to provide seepage control within the embankment, two features were adopted. First, the impervious core, embankment Zone 1, is placed upstream and extended through streambed alluvium and terrace gravels to bedrock to act as a water barrier. The more pervious shell, Zone 4, supports the impervious core zone. The second seepage control feature is the drain chimney and blanket, processed gravel Zone 2 flanked by select gravel zone 4a. This chimney and drain blanket acts to collect all seepage within the embankment and conduct it safely downstream. The chimney drain also acts to reduce danger from cracking of the core, by providing a highly pervious, filter protected zone which can carry water away from cracks while permitting the core and filter to "heal" by washing in fines.

The embankment provides for foundation seepage control in two ways. First by placing the impervious core trench through the streambed alluvium and terrace gravels to bedrock to reduce seepage through those materials. In addition, by placing the impervious core trench upstream, a longer seepage path and reduced gradient is provided through the bedrock. The second foundation seepage control feature is that provided by the drain trenches under the downstream toe of the embankment. These drains trenches collect seepage through the streambed alluvium and terrace gravels, and relieve hydrostatic uplift at the most critical area, the downstream toe of the dam.

The zoning of the dam embankment includes several features which provide for economical usage of natural earth materials. Large amounts of required excavation are included in the High Tongue River Dam design, mainly in the outlet works, spillway, dam foundation and right abutment shaping. Therefore, a large random zone 4 shell has been provided to utilize nearly all the required excavation. A large random zone 4 has been provided in the center of the dam to provide an area for use of early excavation with only minimal foundation preparation. The zone 1 core must be obtained from upstream borrow areas. The use of the processed gravel drain zone 2 has been minimized. The filter zone 4a makes use of unprocessed sand and gravel from terraces or streambed. The zone 3, baked rock or "clinker", zone has been provided for drawdown and erosion protection. This baked rock is readily obtainable from the left abutment ridge above the dam.

EMBANKMENT AND FOUNDATION SEEPAGE

The patterns of embankment and foundation seepage pressures developed for the various cases of stability analysis are shown on Dwg. Nos. 6694-VII-020 through 025. Equipressure lines are used to illustrate the seepage pressure patterns.

The upstream drawdown zone is considered highly pervious when compared to other materials. The core Zone 1 and central random Zone 4 are assumed to have equal low permeability, less than one foot per year. The chimney drain will be highly pervious. The foundation alluvium is considered pervious and the bedrock is considered to have much higher horizontal than vertical permeability due to horizontal siltstone and clay shale layers. The pressure at the downstream toe in the foundation bedrock is considered to be 10 feet higher than the relief well drain header to approximate well entrance hydraulic losses.

STABILITY ANALYSIS

The stability analysis for the combined embankment and foundation was performed using a computerized circular arc method of slices. The method of analysis is illustrated on Dwg. No. 6694-VII-020. The results of the analysis on the final dam section are presented on Dwgs. No. 6694-VII-020 through -025.

Embankment soil parameters for the analysis as shown on the drawings were obtained from soil test data and are summarized below"

Key	Zone	Type Mat'l	Unit Weight lb/cu.Ft. Moist	Saturated	Friction Angle-degrees
A	3	Baked Rock or clinker	77	115	33.5
B	1	Impervious Core	126	135	31.5
C	2,4,4a	Shell,drain & filter	131	131	31.5

Foundation parameters were generally determined from test data and typical data from other projects. However, the strength of the clay shale received some special attention. Because of the difficulty in sampling and obtaining meaningful test data on clay shales, only limited testing was performed. It was found that the clay shale had an Atterberg liquid limit of 51 percent, a plasticity index of 29 percent, and 52 percent smaller than 2 microns. Since shear strength determinations of the clay shale by testing would probably not be valid, indirect methods were used. Several block landslides in the area were analyzed. It was found that they could have failed by sliding on a base of clay shale with a developed friction angle of 20°. Similar values for clay shale shear strength were utilized in the design of Garrison Dam, North Dakota, also located in the Tongue River Member of the Fort Union Formation.

The foundation for the dam consists of layers of coal, sandstones and siltstones. These layers generally lense out in short distances as described in the section "Geology". Therefore, the clay shale is also found in discontinuous layers. The stability analysis had to reflect the field conditions. A wedge type analysis, failing along a horizontal continuous clay shale bed, is therefore, unrealistic. Consequently a circular arc analysis was selected to pass through lenses of clay shale in the foundation. For purposes of analysis, this was done by setting 5 foot thick layers of clay shale in the siltstones and sandstone 30 feet apart. Because the circular arc analysis made by the computer can stay within a five foot thick layer only for a short distance, the effect of lensing is realistically achieved.

A summary of the foundation strength parameters is as follows:

Key	Type Mat'l.	Saturated Unit Weight	Friction Angle Degrees
D	Streambed Alluvium Terrace Gravel	130	30.0
E	Siltstone and sandstone	137	30.0
F	Clay shale	137	20.0

The results of the stability analysis are summarized in the following table.

Section	Condition	Safety Factor Design Criteria	Safety Factor Computed
Upstream - Maximum	Gravity-Seepage	1.50	1.81
Upstream - Maximum	Gravity-Seepage-Seismic	1.10	1.16
Upstream - Maximum	Rapid Drawdown	1.25	1.40
Upstream - Abutment	Gravity-Seepage	1.50	1.81
Upstream - Abutment	Gravity-Seepage-Seismic	1.10	1.12
Downstream-Maximum	Gravity-Seepage	1.50	1.91
Downstream-Maximum	Gravity-Seepage-Seismic	1.10	1.16
Downstream-Abutment	Gravity-Seepage	1.50	1.66
Downstream-Abutment	Gravity-Seepage-Seismic	1.10	1.12

FOUNDATION SEEPAGE CONTROL

Foundation seepage control is partly provided by the embankment design as previously discussed. At the center of the impervious core zone contact with the bedrock, a grout curtain will be installed as detailed on Dwg. No. 6694-VII-005. Relief wells and horizontal pipe drains will be installed along the toe of the dam as shown on Dwgs. No. 6694-VII-004 and 006.

RIGHT ABUTMENT SLIDE AREA

The landslide area at the downstream right abutment toe of the dam will be butressed by the dam embankment. Drains will be installed to relieve seepage pressures behind the slide material. In order to increase the stability of this slide area the right abutment ridge above the slide will be cut back to unload the top of the slope.

INSTRUMENTATION

Instrumentation will be required to determine the performance of the high Tongue River Dam and foundations. Embankment piezometers will be installed to monitor internal seepage pressures. Surface settlement markers and two cross arm internal settlement devices will be installed to monitor the surface settlements and internal distribution of embankment settlements.

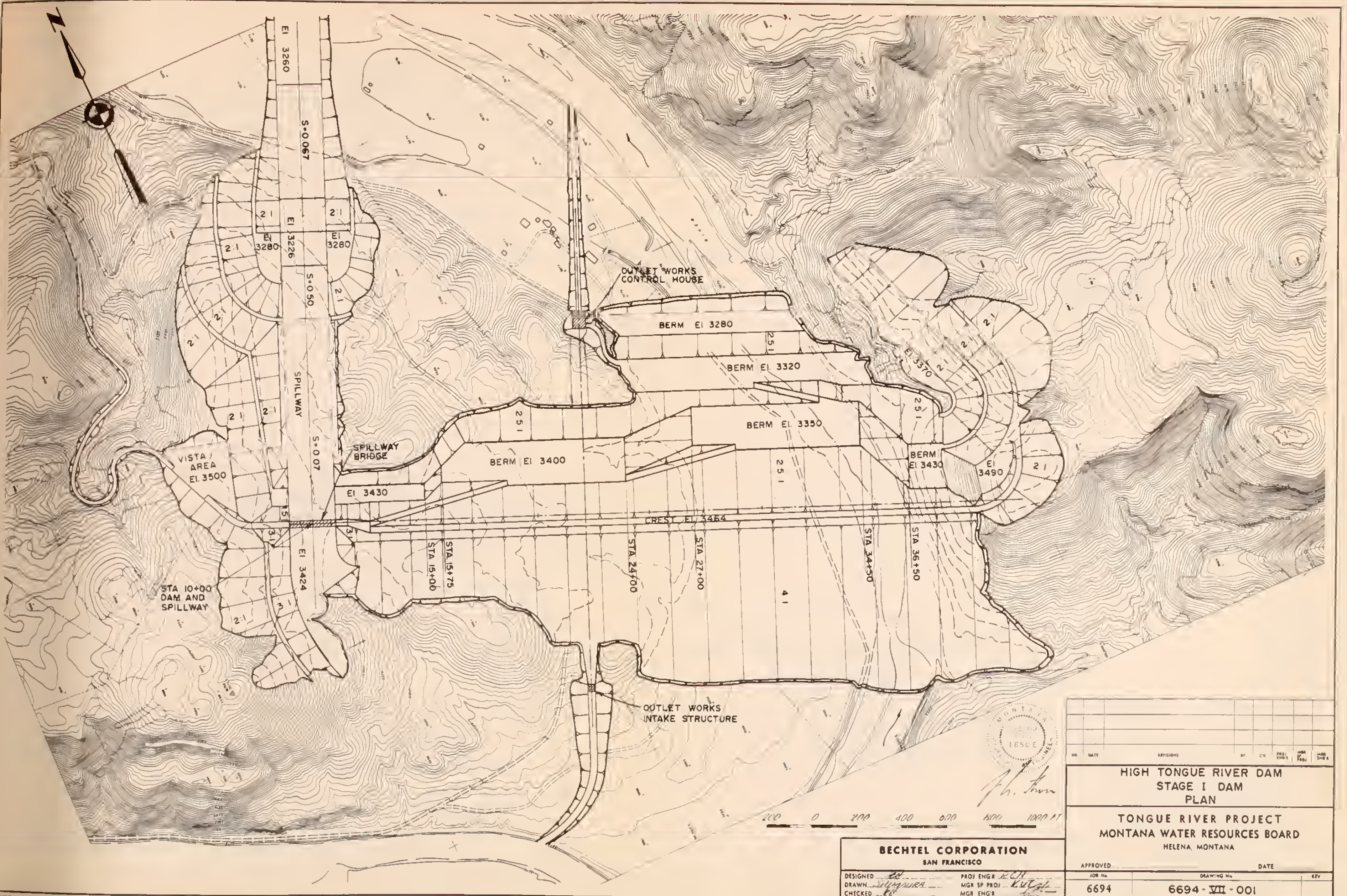
The emphasis on instrumentation however, will be on monitoring foundation seepage in the coal and other pervious members. Open tube type wellpoints will be installed along the toe of the dam and in the abutments to determine the foundation seepage pressures and provide a basis for design of any necessary remedial treatment.

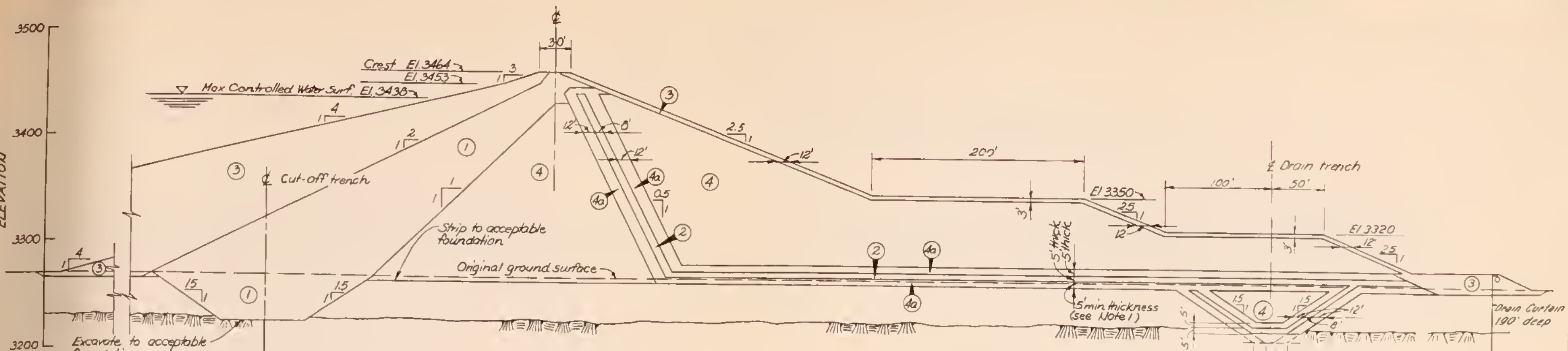
CAMBER

Camber will be provided to allow for anticipated crest settlement of one to two feet and provide for a slightly arched crest so that it will not appear to sag in the middle. Four feet of camber will be provided by oversteepening at the top of the dam, and tapering to no camber at the abutments.

ROADS

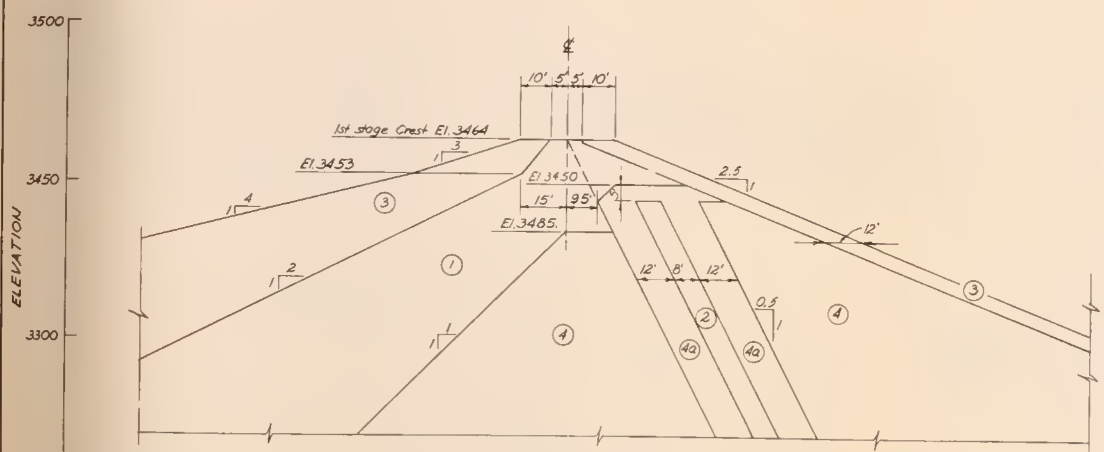
An access road will be provided by improving the existing road from the Decker-Birney road and building a new road to the left abutment of the dam as shown on Dwg. No. 6694-VII-001.


N
EI 3260
S-0.067
2:1
EI 3280
EI 3226
EI 3280
S-0.050
SPILLWAY
S-0.07
SPILLWAY BRIDGE
VISTA AREA EI. 3500
OUTLET WORKS CONTROL HOUSE
BERM EI 3280
BERM EI 3320
BERM EI 3350
BERM EI 3400
EI 3430
EI 3370
BERM EI 3430
EI 3490
2.5:1
CREST EI 3464
1.5
3:1
EI 3424
STA 10+00 DAM AND SPILLWAY
STA 15+00
STA 15+75
STA 24+00
STA 27+00
STA 34+50
STA 36+50
4:1
OUTLET WORKS INTAKE STRUCTURE
200 0 200 400 600 800 1000 FT
HIGH TONGUE RIVER DAM
STAGE I DAM
PLAN
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN
CHECKED
PROJ ENGR
MGR SP PROJ
MGR ENG'R
APPROVED
DATE
JOB No.
6694
DRAWING No.
6694-VII-001



MAXIMUM SECTION

50 0 50 100 150 Ft



CREST DETAILS

20 0 20 40 60 Ft

ZONE — MATERIAL

1. Impervious-from Borrow Areas Q, M, L, K, G & I
2. Processed Sand and Gravel
3. "Clinker" or "Baked Rock"
4. Random-Required Excavation or from Borrow Areas Q, N, H, G and Post Creek
4a. Select Gravelly Fill from Terrace Borrow Area

NOTES:

1. The lower layer of Zone 4a, shall have a thickness of 5 feet where the stripped foundation elevation is 3270 or higher. The thickness shall be increased where the stripped foundation is lower than El 3270 to provide a top of layer elevation of 3275

NO	DATE	REVISIONS	BY	CH'K	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
STAGE I DAM
MAXIMUM SECTION

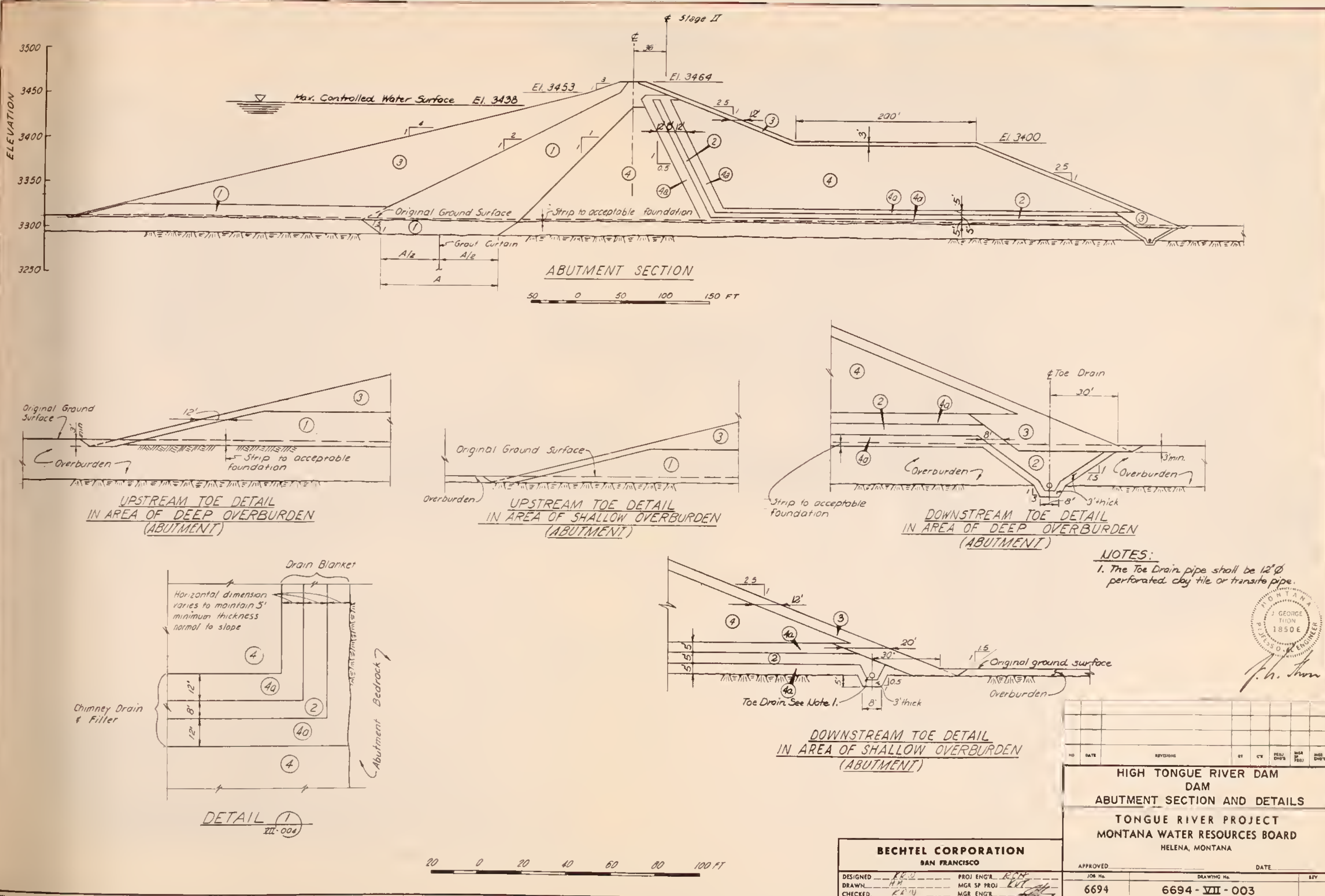
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

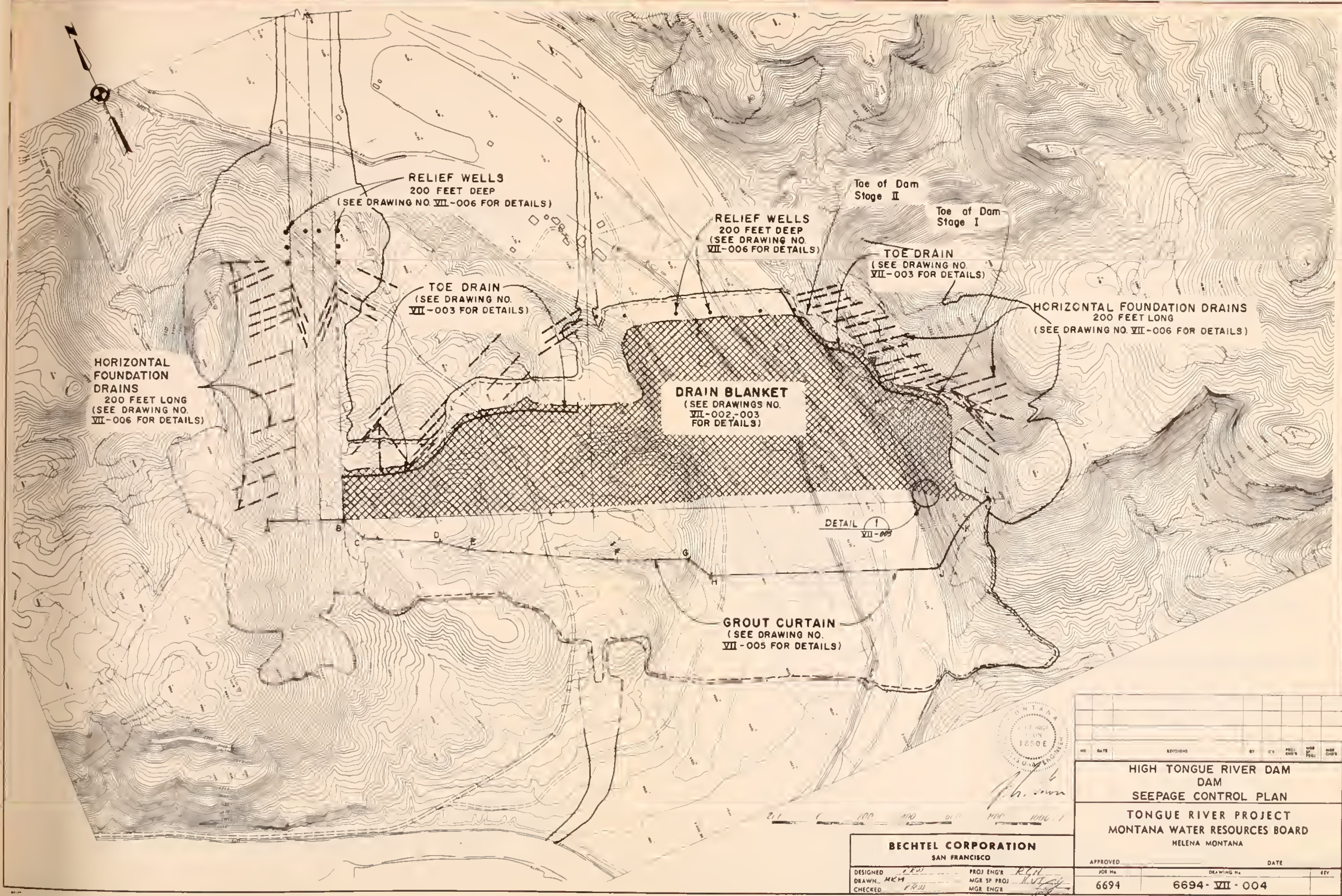
DESIGNED VEO — PROJ ENG'R RCN
DRAWN J.B.M. — MGR SP PROJ KVT
CHECKED KEO — MGR ENG'R

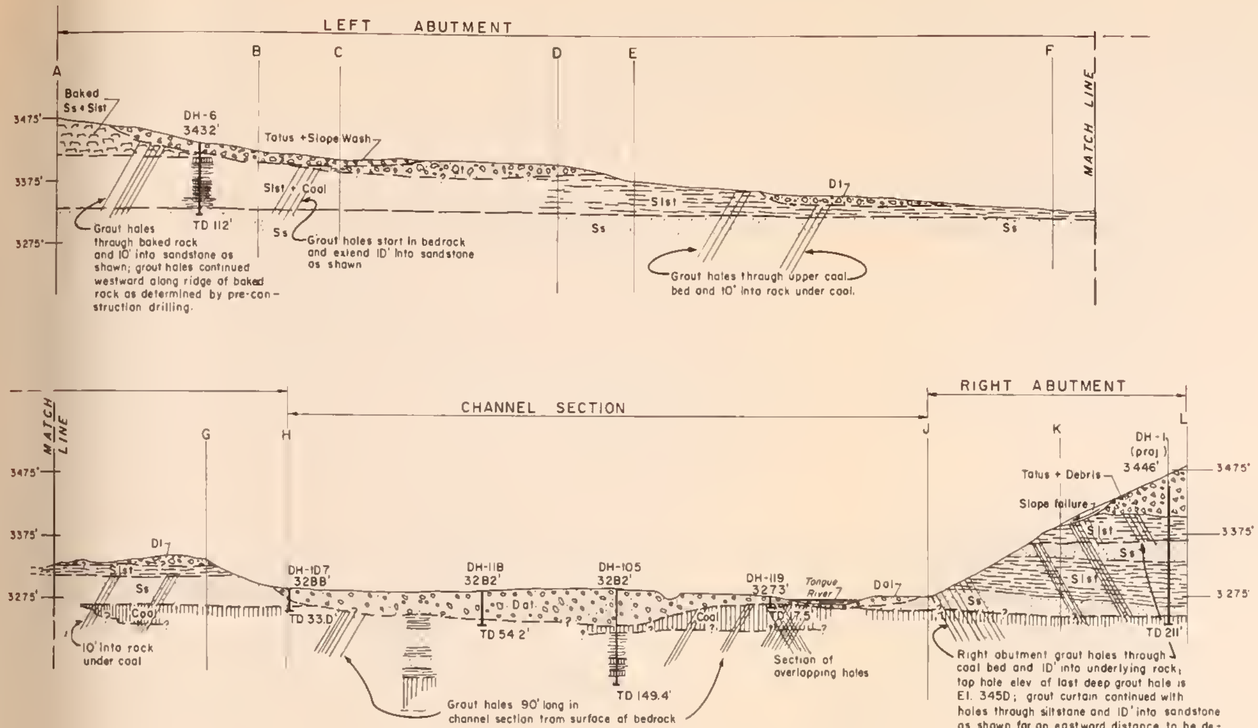
APPROVED — DATE

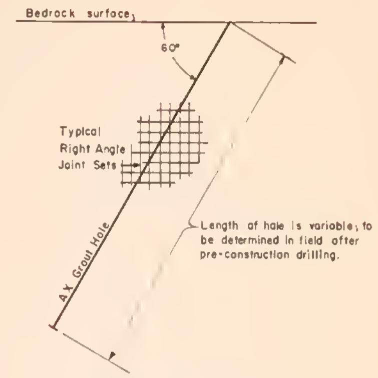
JOB No. 6694 — DRAWING No. 6694-VIII-002 — REV



ABUTMENT SECTION
ELEVATION
3500
3450
3400
3350
3300
3250
℄ Stage II
℄
36
El. 3453
El. 3464
Max. Controlled Water Surface El. 3438
200'
El. 3400
Original Ground Surface
Strip to acceptable foundation
Grout Curtain
A/2
A
50 0 50 100 150 FT
UPSTREAM TOE DETAIL IN AREA OF DEEP OVERBURDEN (ABUTMENT)
Original Ground Surface
Overburden
Strip to acceptable foundation
UPSTREAM TOE DETAIL IN AREA OF SHALLOW OVERBURDEN (ABUTMENT)
Original Ground Surface
Overburden
DOWNSTREAM TOE DETAIL IN AREA OF DEEP OVERBURDEN (ABUTMENT)
℄ Toe Drain
30'
3' min.
Overburden
Strip to acceptable foundation
3' thick
DETAIL 1 VII-004
Drain Blanket
Horizontal dimension varies to maintain 5' minimum thickness normal to slope
Chimney Drain & Filter
Abutment Bedrock
DOWNSTREAM TOE DETAIL IN AREA OF SHALLOW OVERBURDEN (ABUTMENT)
Original ground surface
Overburden
Toe Drain See Note 1.
3' thick
20 0 20 40 60 80 100 FT
NOTES:
1. The Toe Drain pipe shall be 12"Ø perforated clay tile or transite pipe.
HIGH TONGUE RIVER DAM
DAM
ABUTMENT SECTION AND DETAILS
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN
CHECKED
PROJ ENG'R
MGR SP PROJ
MGR ENG'R
APPROVED
DATE
JOB No. 6694
DRAWING No. 6694-VII-003


RELIEF WELLS
200 FEET DEEP
(SEE DRAWING NO. VII-006 FOR DETAILS)
Toe of Dam
Stage II
Toe of Dam
Stage I
RELIEF WELLS
200 FEET DEEP
(SEE DRAWING NO.
VII-006 FOR DETAILS)
TOE DRAIN
(SEE DRAWING NO.
VII-003 FOR DETAILS)
TOE DRAIN
(SEE DRAWING NO.
VII-003 FOR DETAILS)
HORIZONTAL FOUNDATION DRAINS
200 FEET LONG
(SEE DRAWING NO. VII-006 FOR DETAILS)
HORIZONTAL
FOUNDATION
DRAINS
200 FEET LONG
(SEE DRAWING NO.
VII-006 FOR DETAILS)
DRAIN BLANKET
(SEE DRAWINGS NO.
VII-002, 003
FOR DETAILS)
DETAIL 1
VII-003
B
C
D
E
F
G
H
J
K
GROUT CURTAIN
(SEE DRAWING NO.
VII-005 FOR DETAILS)
HIGH TONGUE RIVER DAM
DAM
SEEPAGE CONTROL PLAN
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA MONTANA
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN MKM
CHECKED
PROJ ENG'R
MGR SP PROJ
MGR ENG'R
APPROVED
DATE
JOB No
DRAWING No
6694
6694-VII-004





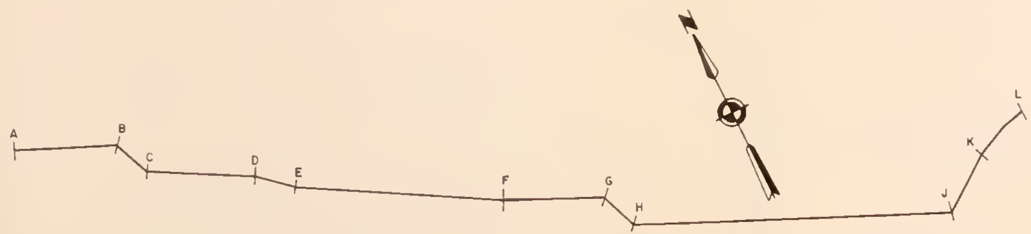
TYPICAL GROUT HOLE DETAILS

NOTES:

1. Elevations shown are views looking downstream
2. All alluvium, slope failure material, talus, slope wash and unconsolidated debris in core trench and along grout curtain will be removed
3. It is anticipated that grout holes will generally be spaced at 5 feet centers in a single curtain. Between section A–C, a double curtain may be required as determined by the Engineer

100' 0 100' 200' 300' 400'

VERTICAL & HORIZONTAL SCALE



GROUT CURTAIN - PLAN

SCALE: 1" = 200'

NO	DATE	REVISIONS	BY	CK'D	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
DAM
GROUTING DETAILS

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED ______ DATE ______

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED ______ PROJ ENGR ______
DRAWN ______ MGR SP PROJ ______
CHECKED ______ MGR ENG'R ______

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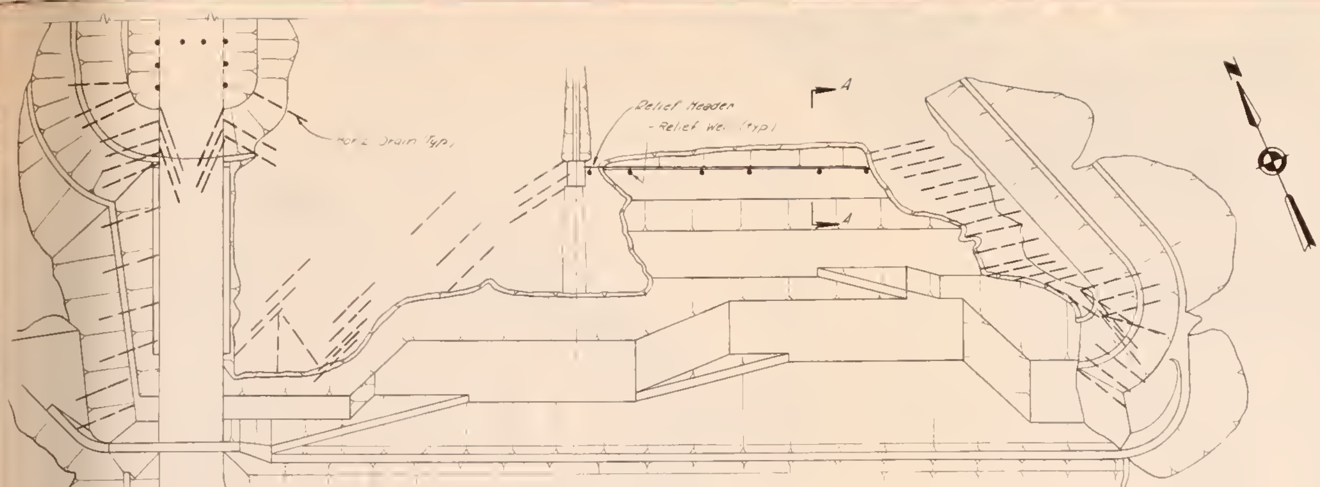
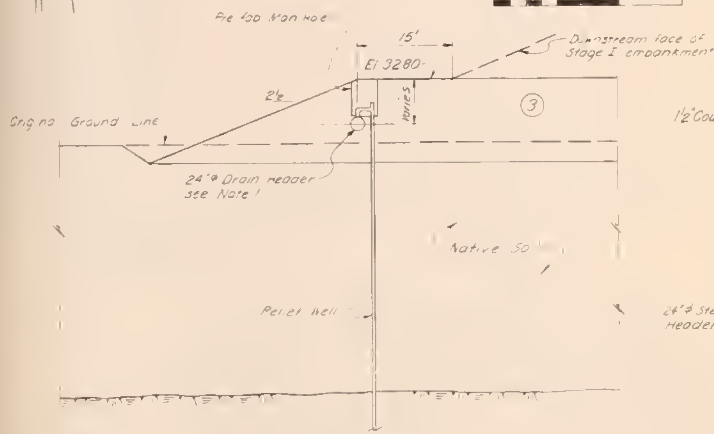


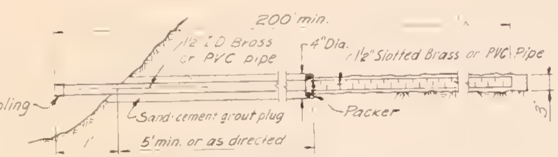
PARTIAL PLAN

200 0 200 400 Ft

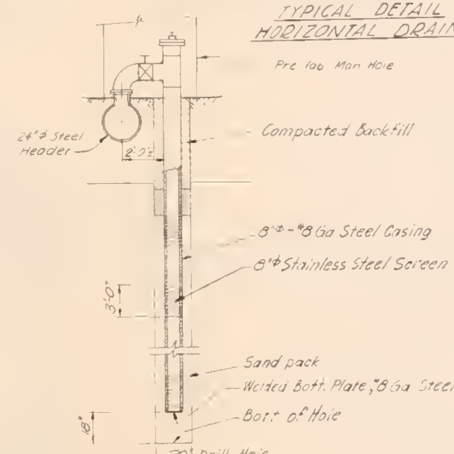


SECTION A-A

10 0 0 20 30 Ft



TYPICAL DETAIL
HORIZONTAL DRAIN



RELIEF WELL - DOWNSTREAM
TOE OF DAM (See Note 2)
NTS

NOTES

1. Slope Relief Well drain header 0.5% to discharge at Elevation 3268 at outlet works.
2. Relief Well at Spillway similar to Relief Well at Downstream Toe of Dam except as shown and noted on Dwg 6694-VIII-010
3. Locations also shown on Dwg 6694-VII-004

NO	DATE	REVISIONS	BY	CK	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
DAM
DRAINAGE DETAILS

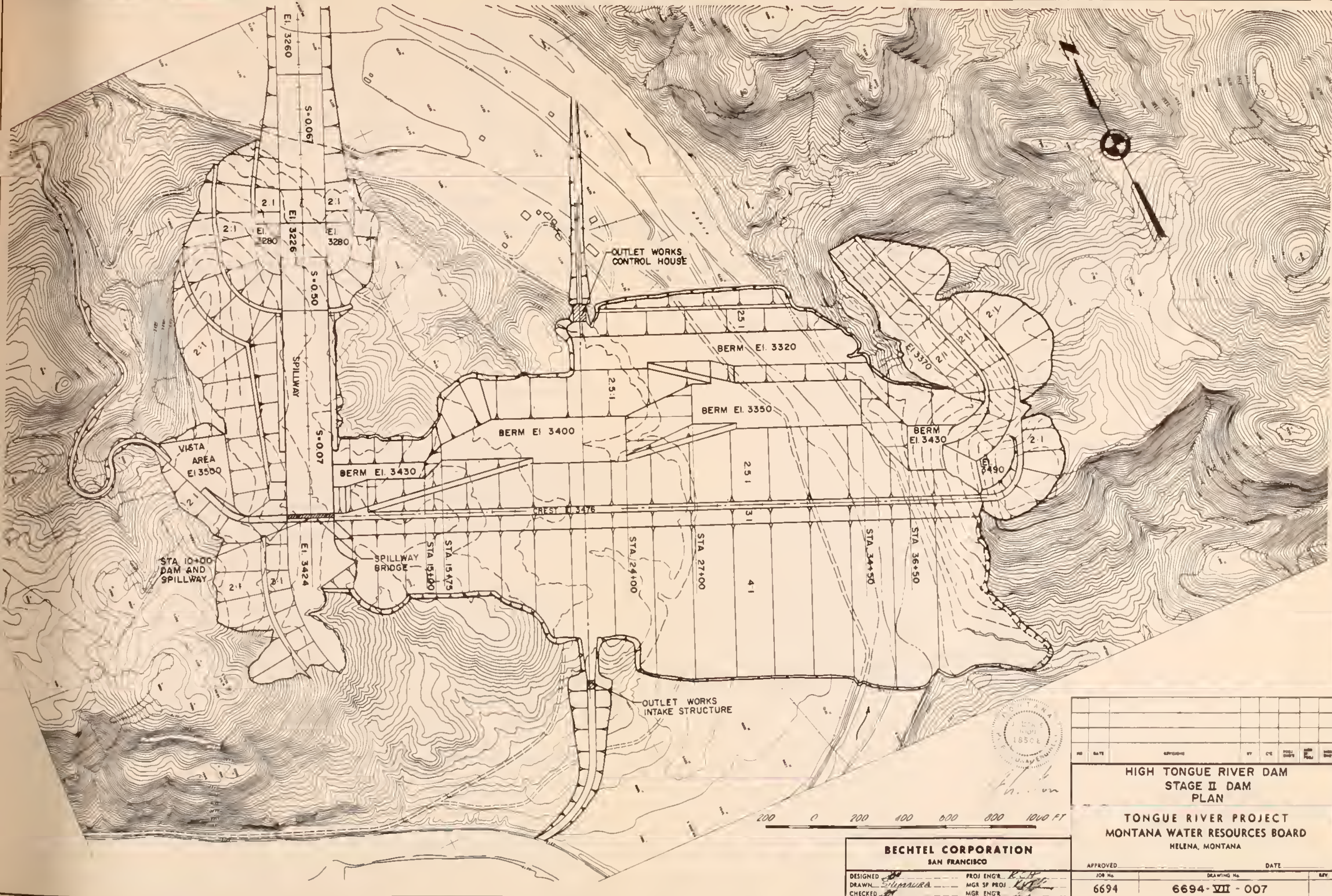
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

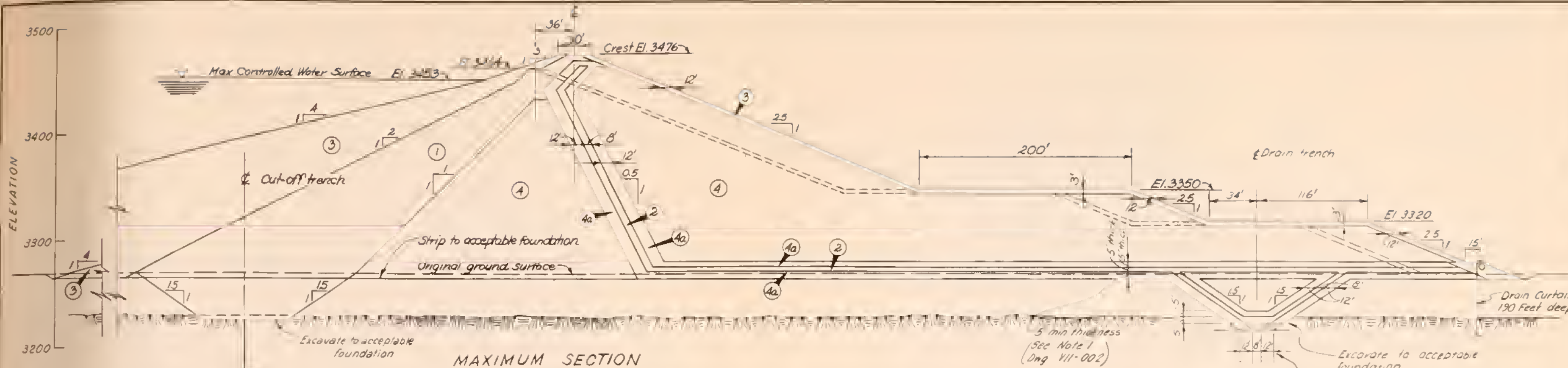
DESIGNED E.J. — PROJ ENG'R K.C.N.
DRAWN H.W.T. — MGR SP PROJ
CHECKED F.R.W. — MGR ENG'R

APPROVED — DATE

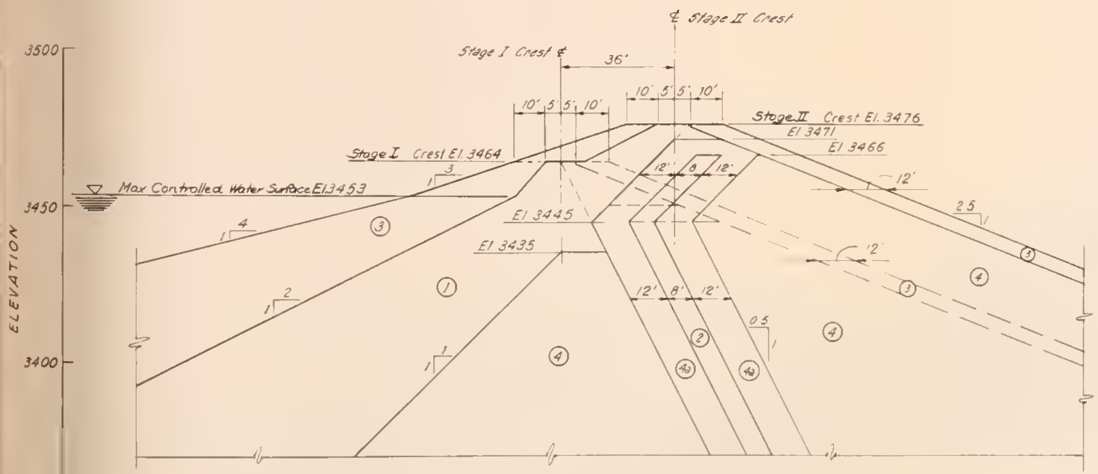
JOB No	DRAWING No	REV
6694	6694 - VII - 006	



El. 3260
S=0.067
2:1
El. 3280
El. 3226
S=0.50
SPILLWAY
S=0.07
OUTLET WORKS CONTROL HOUSE
BERM El. 3320
BERM El. 3350
BERM El. 3400
BERM El. 3430
BERM El. 3430
El. 3370
El. 3490
2.5:1
3:1
4:1
VISTA AREA El. 3500
CREST El. 3476
STA 10+00 DAM AND SPILLWAY
El. 3424
SPILLWAY BRIDGE
STA 15+00
STA 15+75
STA 24+00
STA 27+00
STA 34+50
STA 36+50
OUTLET WORKS INTAKE STRUCTURE
200 0 200 400 600 800 1000 FT
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN
CHECKED
PROJ ENG'R
MGR SP PROJ
MGR ENG'R
HIGH TONGUE RIVER DAM
STAGE II DAM
PLAN
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
APPROVED
DATE
6694
6694-VII-007



MAXIMUM SECTION



CREST DETAILS

ZONE	MATERIAL
1	Impervious - from Borrow Areas R, M, L, K, G & I
2	Processed Sand and Gravel
3	"Clinker" or "Baked Rock"
4	Random - Required Excavation or from Borrow Areas R, N, M, G and Post Creek
4a	Select Gravelly Fill from Terrace Borrow Areas

HIGH TONGUE RIVER DAM
STAGE II DAM
MAXIMUM SECTION

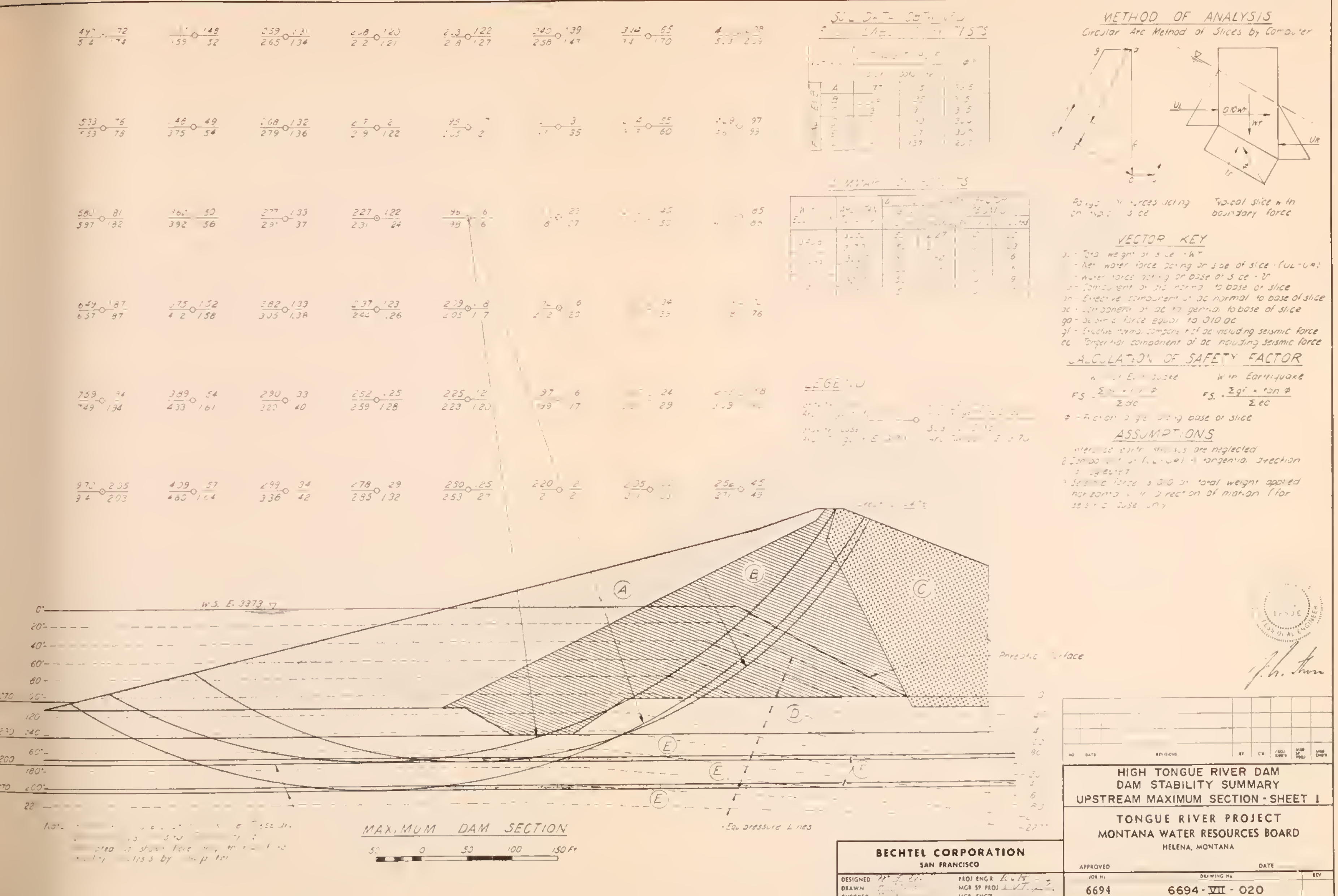
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

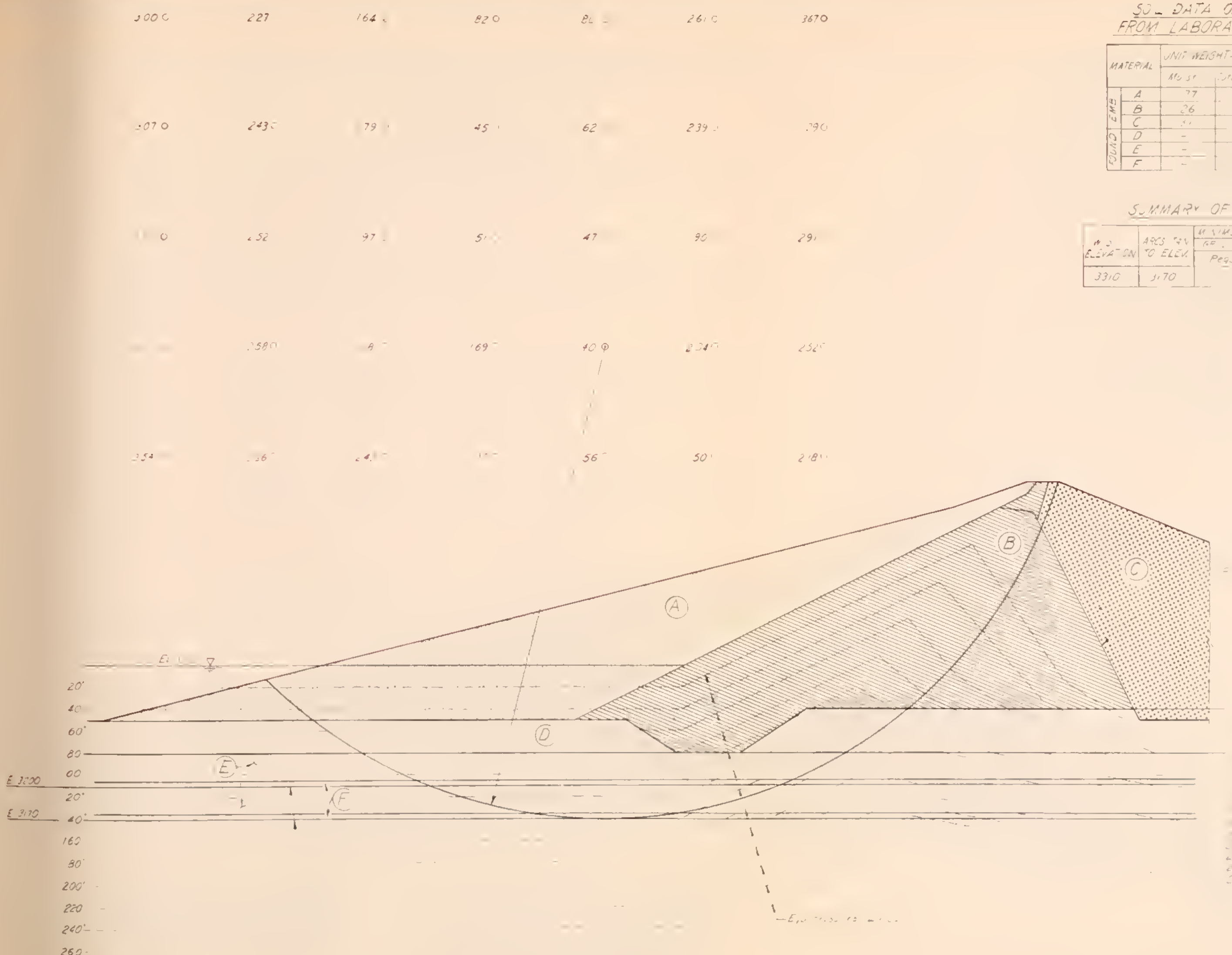
DESIGNED KRW — PROJ ENG'R RGH
DRAWN J.B.M — MGR SP PROJ
CHECKED KRW — MGR ENG'R

APPROVED — DATE

JOB No. 6694 — DRAWING No. 6694-VII-008



METHOD OF ANALYSIS
Circular Arc Method of Slices by Computer
Typical slice with boundary force
VECTOR KEY
CALCULATION OF SAFETY FACTOR
With Earthquake
ASSUMPTIONS
LEGEND
W.S. E. 3373
Phreatic Surface
Equipressure Lines
MAXIMUM DAM SECTION
50 0 50 100 150 Ft
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN
CHECKED
PROJ ENGR
MGR SP PROJ
MGR ENGR
HIGH TONGUE RIVER DAM
DAM STABILITY SUMMARY
UPSTREAM MAXIMUM SECTION - SHEET 1
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
APPROVED
DATE
6694
6694 - VII - 020



MAXIMUM DAM SECTION

Note: Foundation layers of clay ... These are discontinuous ... continuity is simulated as shown ... to facilitate stability analysis by computer.

SOIL DATA OBTAINED FROM LABORATORY TESTS

MATERIAL		UNIT WEIGHT - PCF Moist	UNIT WEIGHT - PCF Saturated	$\phi°$
EMB	A	[illegible]	[illegible]	33.5
EMB	B	26	35	[illegible]
EMB	C	[illegible]	[illegible]	[illegible]
FOUND	D	–	30	[illegible]
FOUND	E	–	37	[illegible]
FOUND	F	–	37	[illegible]

SUMMARY OF RESULTS

W.S. ELEVATION	ARCS TAN TO ELEV.	MINIMUM SAFETY FACTOR — STABILITY WITH RAPID DRAWDOWN Required	MINIMUM SAFETY FACTOR — STABILITY WITH RAPID DRAWDOWN Computed
3310	3170	25	40

NO	DATE	REVISIONS	BY	CH	PROJ ENGR	MGR SP PROJ	MGR ENGR

HIGH TONGUE RIVER DAM
DAM STABILITY SUMMARY
UPSTREAM MAXIMUM SECTION - SHEET 2

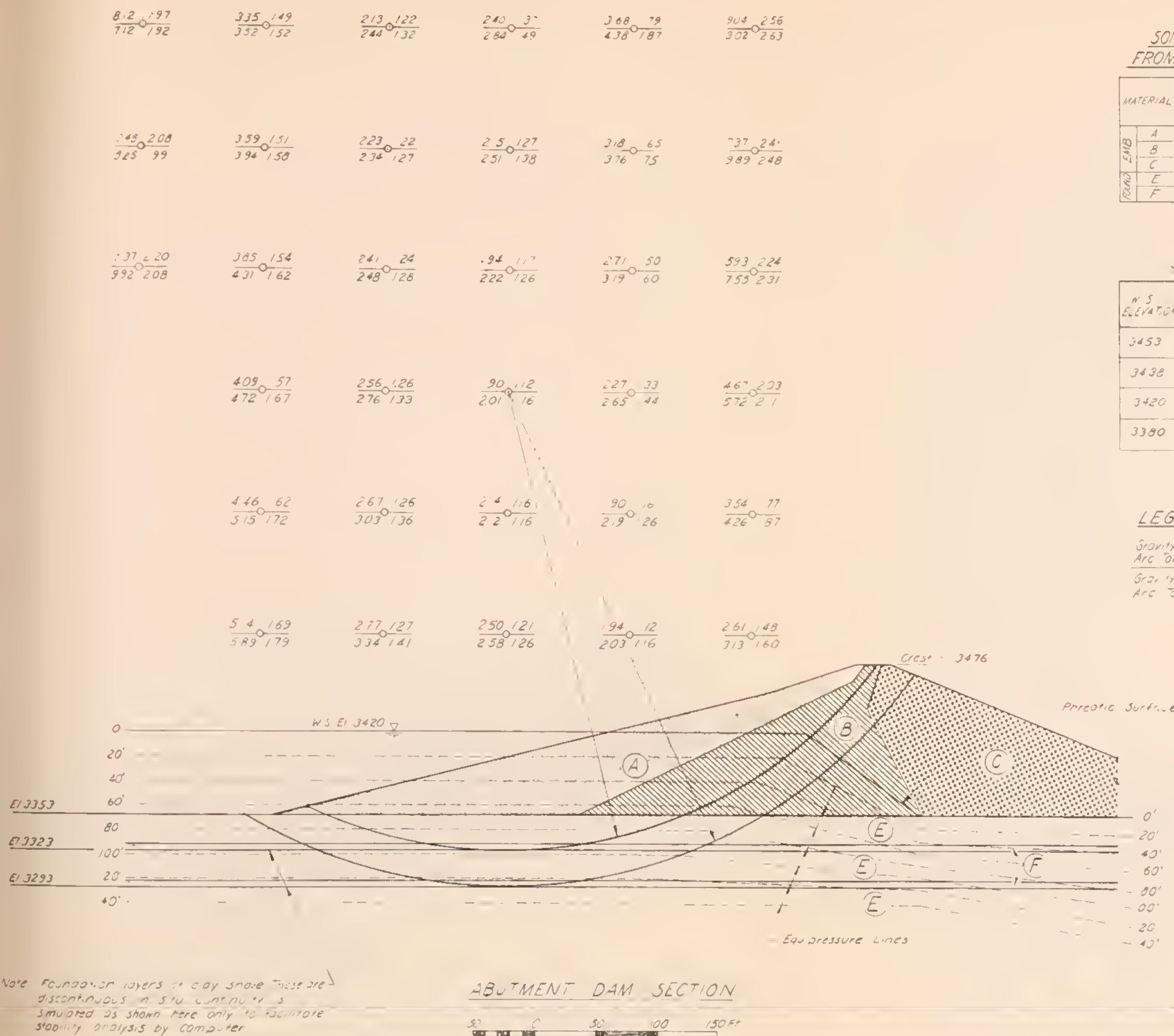
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED — PROJ ENG'R
DRAWN — MGR SP PROJ
CHECKED — MGR ENG'R

APPROVED — DATE

JOB No. 6694 — DRAWING No. 6694 - VII - 021 — REV



Note Foundation layers of clay shale. These are discontinuous in situ, continuity is simulated as shown here only to facilitate stability analysis by Computer

ABUTMENT DAM SECTION

SOIL DATA OBTAINED FROM LABORATORY TESTS

MATERIAL		UNIT WEIGHT - PCF		$\phi°$
		Moist	Saturated	
EMB	A	77	115	335
	B	126	135	3. 5
	C	131	31	315
FOUND	E	-	137	300
	F	-	137	200

SUMMARY OF RESULTS

W S ELEVATION	ARCS TAN TO ELEV	MINIMUM SAFETY FACTOR			
		GRAVITY		SEISMIC	
		Required	Computed	Required	Computed
3453	3323	150	214	110	115
	3293	.50	229	110	122
3438	3323	150	203	110	13
	3293	.50	2.6	110	19
3420	3323	150	190	110	112
	3293	1.50	201	1.10	116
3380	3323	150	181	110	118
	3293	150	185	110	116

LEGEND

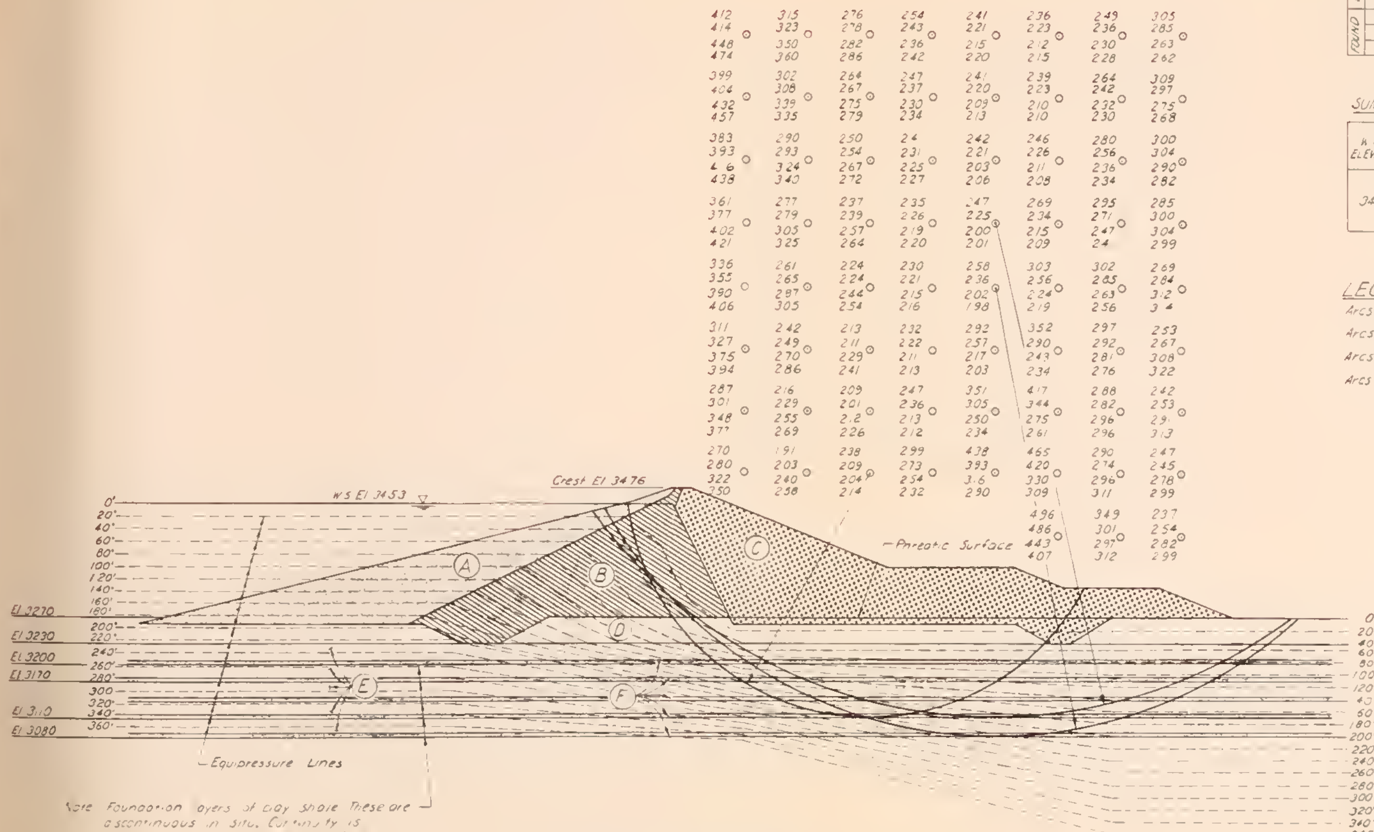
Gravity Case Arc Tangent to El 3200 — Seismic Case Arc Tangent to El 3200

Gravity Case Arc Tangent El 3170 — Seismic Case Arc Tangent El 3170

NOTES

1. See Drawing No 6694 - VII - 020 for a description of the method of analysis and assumptions

BECHTEL CORPORATION SAN FRANCISCO	HIGH TONGUE RIVER DAM DAM STABILITY SUMMARY UPSTREAM ABUTMENT SECTION
DESIGNED / DRAWN / CHECKED PROJ ENG'R / MGR SP PROJ / MGR ENG'R	TONGUE RIVER PROJECT MONTANA WATER RESOURCES BOARD HELENA, MONTANA
	APPROVED / DATE
	JOB No. 6694 — DRAWING No. 6694 - VII - 022 — REV



MAXIMUM DAM SECTION

20 0 100 200 300 Ft

SOIL DATA OBTAINED FROM LABORATORY TESTS

MATERIAL		UNIT WEIGHT - PCF		φ°
		Moist	Saturated	
EMB	A	77	115	335
EMB	B	26	135	315
EMB	C	131	131	315
FOUND	D	—	130	300
FOUND	E	-	137	300
FOUND	F	—	137	200

SUMMARY OF RESULTS

W S ELEVATION	ARCS TAN TO ELEV	MIN SAFETY FACTOR GRAVITY	
		Required	Computed
3453	3200	150	19
	3170	150	201
	3110	150	200
	3080	150	198

LEGEND: Gravity Case

Arcs tangent to El 3200 — 247
Arcs tangent to El 3170 — 225
Arcs tangent to El 3110 — 200
Arcs tangent to El 3080 — 201

NOTES

1 See Drawing No 6694-VII-020 for a description of the method of analysis and assumptions

HIGH TONGUE RIVER DAM
DAM STABILITY SUMMARY
DOWNSTREAM MAXIMUM SECTION - SHEET 1

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED ______ DATE ______

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED ______ PROJ ENG'R ______
DRAWN ______ MGR SP PROJ ______
CHECKED ______ MGR ENG'R ______

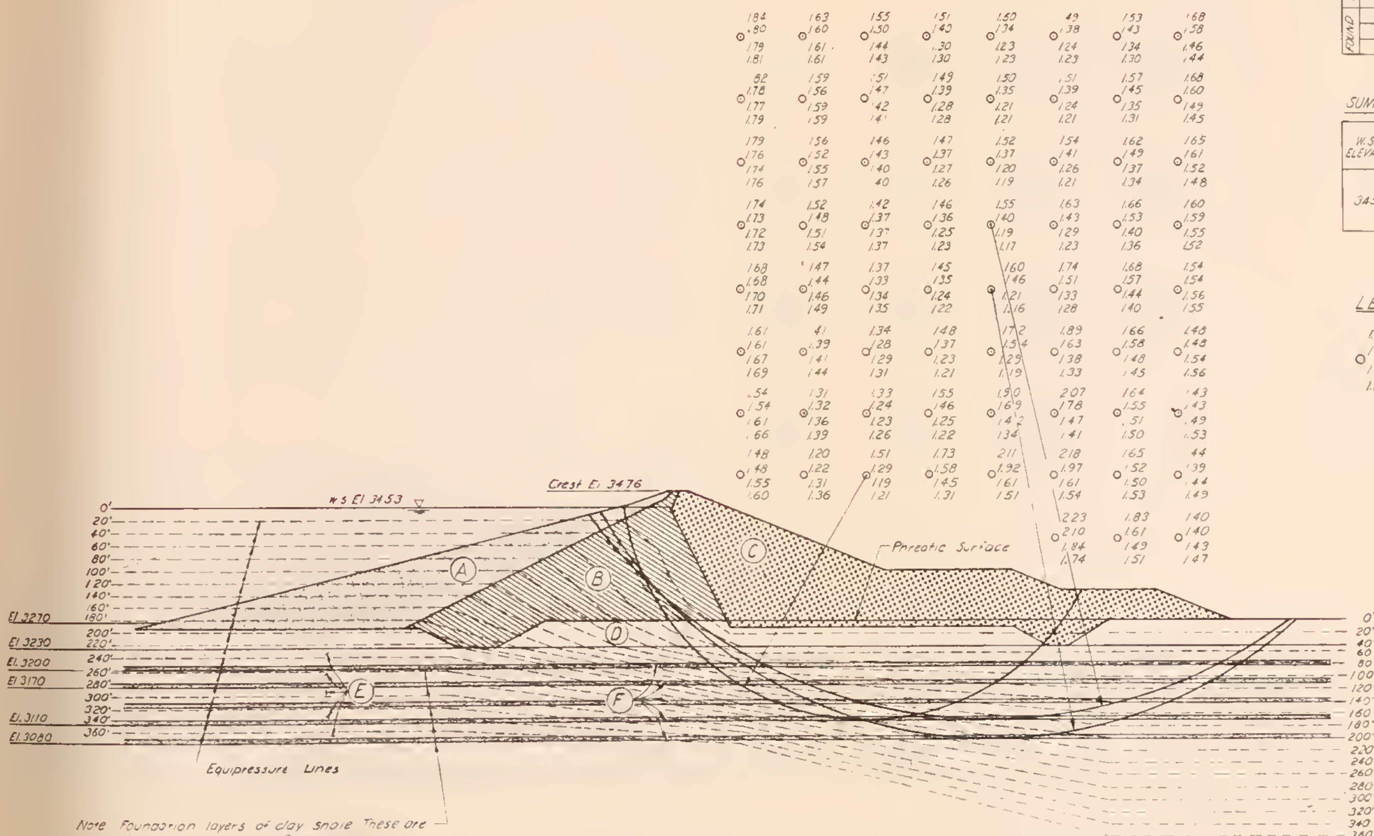
JOB No	DRAWING No	REV
6694	6694 - VII - 023	

SOIL DATA OBTAINED FROM LABORATORY TESTS

	MATERIAL	UNIT WEIGHT - PCF Moist	UNIT WEIGHT - PCF Saturated	Ø°
EMB	A	77	115	33.5
	B	126	135	31.5
	C	131	131	31.5
FOUND	D	–	130	30.0
	E	–	137	30.0
	F	–	137	20.0

SUMMARY OF RESULTS

W.S. ELEVATION	ARCS TAN TO ELEV	MIN SAFETY FACTOR SEISMIC Required	MIN SAFETY FACTOR SEISMIC Computed
3453	3200	1.10	1.20
	3170	1.10	1.22
	3110	1.10	1.19
	3080	1.10	1.16



Note: Foundation layers of clay shale. These are discontinuous in situ. Continuity is simulated as shown here only to facilitate stability analysis by computer.

MAXIMUM DAM SECTION

100 0 100 200 300 Ft.

LEGEND: Seismic Case

1.55 — Arcs tangent to El 3200
1.40 — Arcs tangent to El 3170
1.19 — Arcs tangent to El 3110
1.17 — Arcs tangent to El 3080

NOTES:

1. See Drawing No 6694-VII-020 for a description of the method of analysis and assumptions.

MONTANA J. GEORGE THON 1850 E PROFESSIONAL ENGINEER

HIGH TONGUE RIVER DAM
DAM STABILITY SUMMARY
DOWNSTREAM MAXIMUM SECTION - SHEET 2

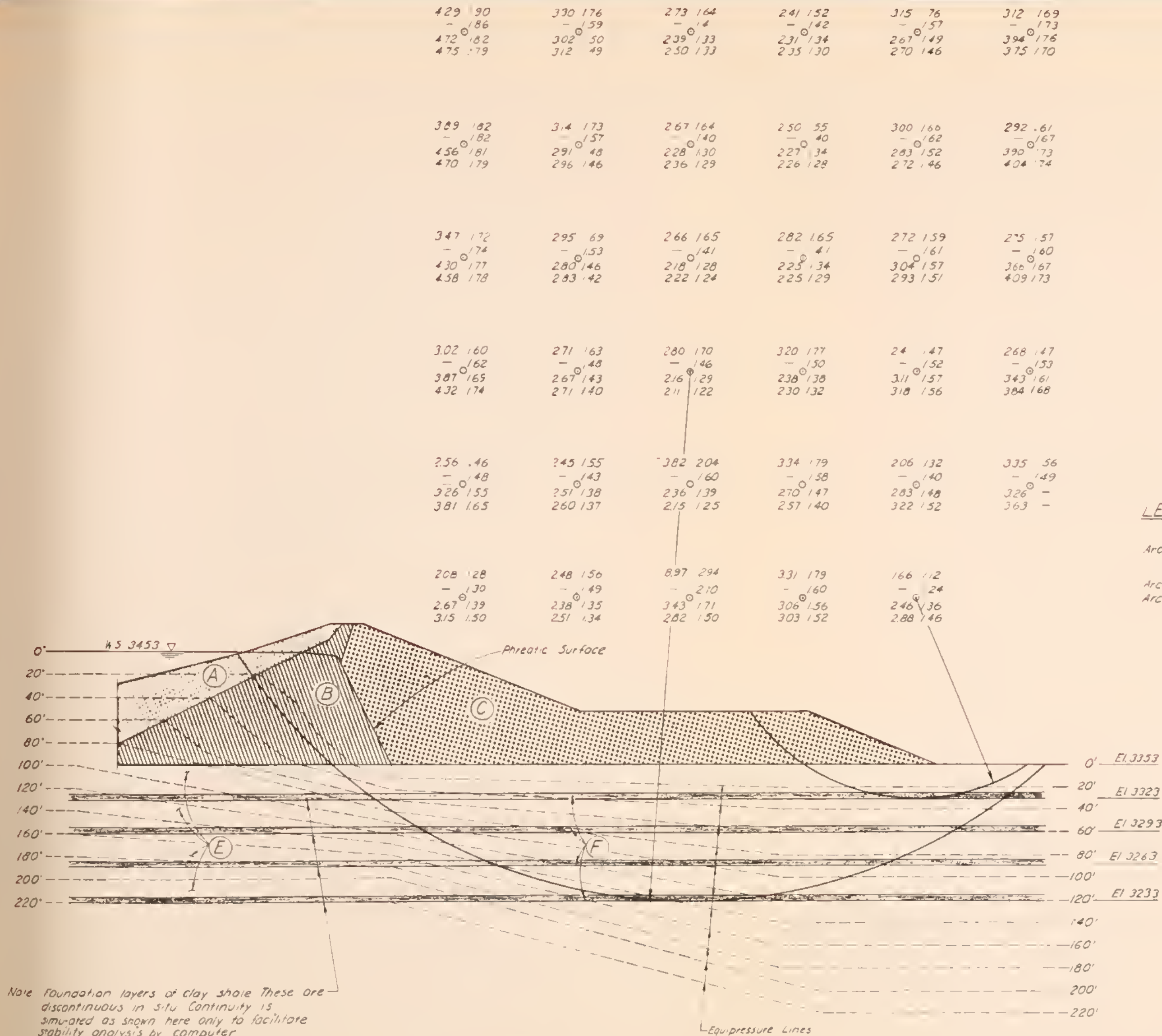
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED ____ PROJ ENG'R ____
DRAWN H. Mitchell MGR SP PROJ ____
CHECKED ____ MGR ENG'R ____

APPROVED ____ DATE ____

JOB No. 6694 DRAWING No. 6694-VII-024 REV.



ABUTMENT DAM SECTION

50 0 50 100 150 Ft

SOIL DATA OBTAINED FROM LABORATORY TESTS

MATERIAL		UNIT WEIGHT - PCF Moist	UNIT WEIGHT - PCF Saturated	$\phi°$
EMB.	A	117	115	33.5
EMB.	B	126	135	31.5
EMB.	C	131	131	31.5
FOUND.	E	–	137	30.0
FOUND.	F	–	137	20.0

SUMMARY OF RESULTS

W S ELEVATION	ARCS TAN TO ELEV.	MINIMUM SAFETY FACTOR GRAVITY Required	GRAVITY Computed	SEISMIC Required	SEISMIC Computed	REMARKS
3453	3323	1.50	2.08 1.66	1.10	1.28 1.12	Deep seated Arc Toe Failure
	3293	1.50	–	1.10	1.30 1.24	Deep seated Arc Toe Failure
	3263	1.50	2.16	1.10	1.28	–
	3233	1.50	2.11	1.10	1.22	–

LEGEND

Gravity Case — Seismic Case

Arcs tangent to El 3323 ⟶ 280 170 ⟵ Arcs tangent to El 3323
— 146 ⟵ Arcs tangent to El 3293
Arcs tangent to El 3263 ⟶ 216 129 ⟵ Arcs tangent to El 3263
Arcs tangent to El 3233 ⟶ 211 122 ⟵ Arcs tangent to El 3233

NOTES

1 See Drawing No 6694-VII-020 for a description of the method of analysis and assumptions

NO	DATE	REVISIONS	BY	CK	PROJ ENGR	MGR SP PROJ	MGR ENGR

HIGH TONGUE RIVER DAM
DAM STABILITY SUMMARY
DOWNSTREAM ABUTMENT SECTION

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED M. T. Thiel — PROJ ENGR RGH
DRAWN H Mitchell — MGR SP PROJ KVT
CHECKED M Thiel — MGR ENGR

APPROVED ____ DATE ____

JOB No 6694 — DRAWING No 6694-VII-025 — REV

VIII. SPILLWAY

GENERAL

The spillway is located on the left abutment of the dam. A plan and profile of the spillway are shown on Drawings No. 6694-VIII-001 and -002. An ungated 200-foot long ogee crest is provided for both first and second stage construction. The decision to construct the dam in two stages had a significant influence on the spillway design. The Stage 1 construction will provide a maximum storage water surface of Elevation 3438. A cost analysis of dam height versus spillway configuration provided an economical combination of a 200-foot long spillway crest, maximum water surface for PMF discharge of 3462 and dam crest 3464. Design spillway outflow for Stage 1 is 94,000 cfs.

For second stage construction 450,000 acre feet of gross storage is required. This establishes the reservoir storage level at Elevation 3453, and the corresponding second stage dam crest at Elevation 3476 with flood pool at Elevation 3474. The flood routing study showed that maximum second stage spillway discharge will be 80,000 cfs.

HYDRAULIC DESIGN

Design of the spillway crest thus required a first stage ogee which would discharge 94,000 cfs at crest Elevation 3438; and was capable of being raised to crest Elevation 3453 with a discharge capability of 80,000 cfs. The ogee design was based on Corps of Engineers' Hydraulic Design Criteria(1) using design heads of 21.0 feet for Stage 1 and 15.75 feet for Stage 2. The resulting maximum coefficients of discharge were 4.00 for Stage 1 and 4.13 for Stage 2.

Water surface profile for the spillway chute was computed using Manning's "n" equals 0.015.

Configuration of the stilling basin was determined by use of Bureau of Reclamation Criteria for a Type II basin.(2) The basin elevation was set to ensure that the jump D_2 elevation would be below the tailwater elevation at all discharges.

STRUCTURAL DESIGN

Structural design of the spillway was based on Corps of Engineers' Criteria(3) using the following loading conditions:

Maximum allowable bearing pressures
- Approach walls not on rock = 2 Tons/sq.ft. plus overburden pressure.
- All walls on rock = 6 Tons/sq.ft.

Lateral earth pressures

Approach walls and high walls at crest: (Counterforted)
Saturated density 135 lb./cu.ft. - earth pressure coefficient 0.60.

Chute walls (Cantilever walls downstream of crest):
Saturated density 130 lb./cu.ft. - earth pressure coefficient 0.35.

High walls at stilling basin (Counterforted):
Saturated density 130 lb./cu.ft. - earth pressure coefficient 0.5.

Concrete

Minimum compressive strength at 28 days - 3000 lb./sq.in.
Maximum allowable stress in flexure - 1350 lb./sq.in.

Reinforcement - Maximum allowable tensile stress - 24,000 lb./sq.in.

As mentioned above, the ogee and upper chute walls will be constructed in two stages; however, all other spillway features are built to their ultimate configuration during first stage construction as shown on Dwg.No.6694-VIII-002.

The ogee is founded on rock at approximate Elevation 3405, some 17 feet below the base of the approach channel. A shear key and seepage cutoff is provided at the upstream face of the ogee.

For second stage construction, the ogee crest will be raised to Elevation 3453. At the time of second stage construction the first stage crest will be stepped, and dowels will be provided to assure complete bond between the first and second stage concrete. The raised crest details are shown on Dwgs. No. 6694-VIII-002 and 012.

A 200-foot long clear span plate girder bridge designed for H-20 loading provides a 12-foot roadway across the spillway crest at the second stage dam crest elevation as shown on Dwg. No.6694-VIII-11.

Counterforted approach walls with stepped footings are provided upstream of the spillway crest. These walls vary in height from 66 feet to 22 feet. For layout of the approach and abutment walls, see Drawings 6694-VIII-004 and -005.

A 200-foot wide, 1117-foot long rectangular chute conveys spillway discharges from the crest to the stilling basin. The upstream 880 feet of the chute is on a 7 percent grade approximately parallel to the natural ground surface; the remainder is on a 50 percent grade, terminating at the stilling basin floor. The chute is provided with L shaped cantilever walls 14 feet high in the upper reach and 12 feet high in the lower reach. These heights allow approximately six feet of freeboard at maximum discharge. The chute floor is a pattern of 30 foot by 30 foot, 18 inch thick slabs. In addition, the slabs are secured

to the foundation with twelve-foot long anchor bars spaced as shown. The chute is shown on Drawings 6694-VIII-006 and -007.

The 200-foot wide by 150-foot long rectangular stilling basin has 55 feet high counterforted side walls. The stilling basin floor is composed of 30-foot by 30-foot, 4-foot thick slabs provided with keys and waterstops at all joints. Fifty percent of the reinforcement is run through the joints. The slabs are anchored to the foundation by No. 11 bars in a 5-foot by 10-foot pattern. The bars are embedded 15 feet minimum into the foundation rock. Chute blocks, armored baffle blocks and an end sill are provided. Stilling basin layout and details are shown on Drawings 6694-VIII-008 and -009.

The entire spillway is protected from hydrostatic uplift by a system of underdrains. Beginning at the crest structure, a 6-inch diameter cross drain is located behind the shear key. This drain is tied to two 12-inch diameter longitudinal drains spaced 50 feet each side of the spillway centerline. The longitudinal drains extend the full length of the chute and at their lower end are turned laterally to discharge through the stilling basin walls. Along the chute six-inch diameter cross drains are provided at 60-foot spacing. As protection against freezing, and to assure collection of seepage water, the drains are located in 6-foot deep trenches which are backfilled with pervious material.

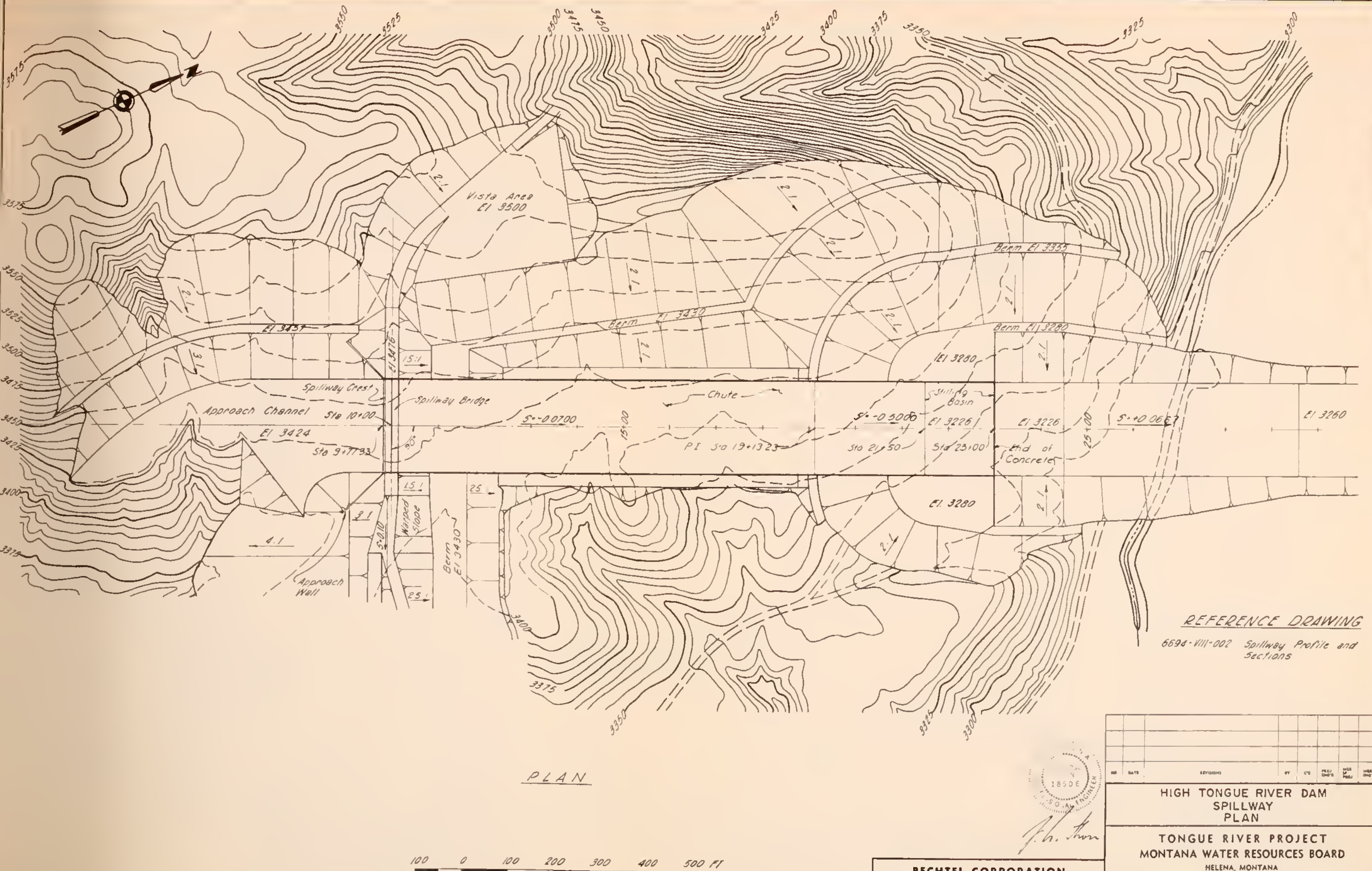
In addition to the underdrains, 8-inch diameter longitudinal drains are provided behind the chute and stilling basin walls. These are located approximately at foundation level and are daylighted through the stilling basin walls. Relief wells are provided around the stilling basin to protect against deep seated uplift. Drainage details are shown on Dwg. No. 6694-VIII-010.

REFERENCES

(1) U. S. Corps of Engineers' Hydraulic Design Criteria - Waterways Experiment Station, Vicksburg, Mississippi.

(2) Bureau of Reclamation "Design of Small Dams", 1960, Section 199, Hydraulic Jump Basin.

(3) U. S. Corps of Engineers, EM-1110-2-2400, Structural Design of Spillways and Outlet Works, November 1964.



HIGH TONGUE RIVER DAM
SPILLWAY
PLAN

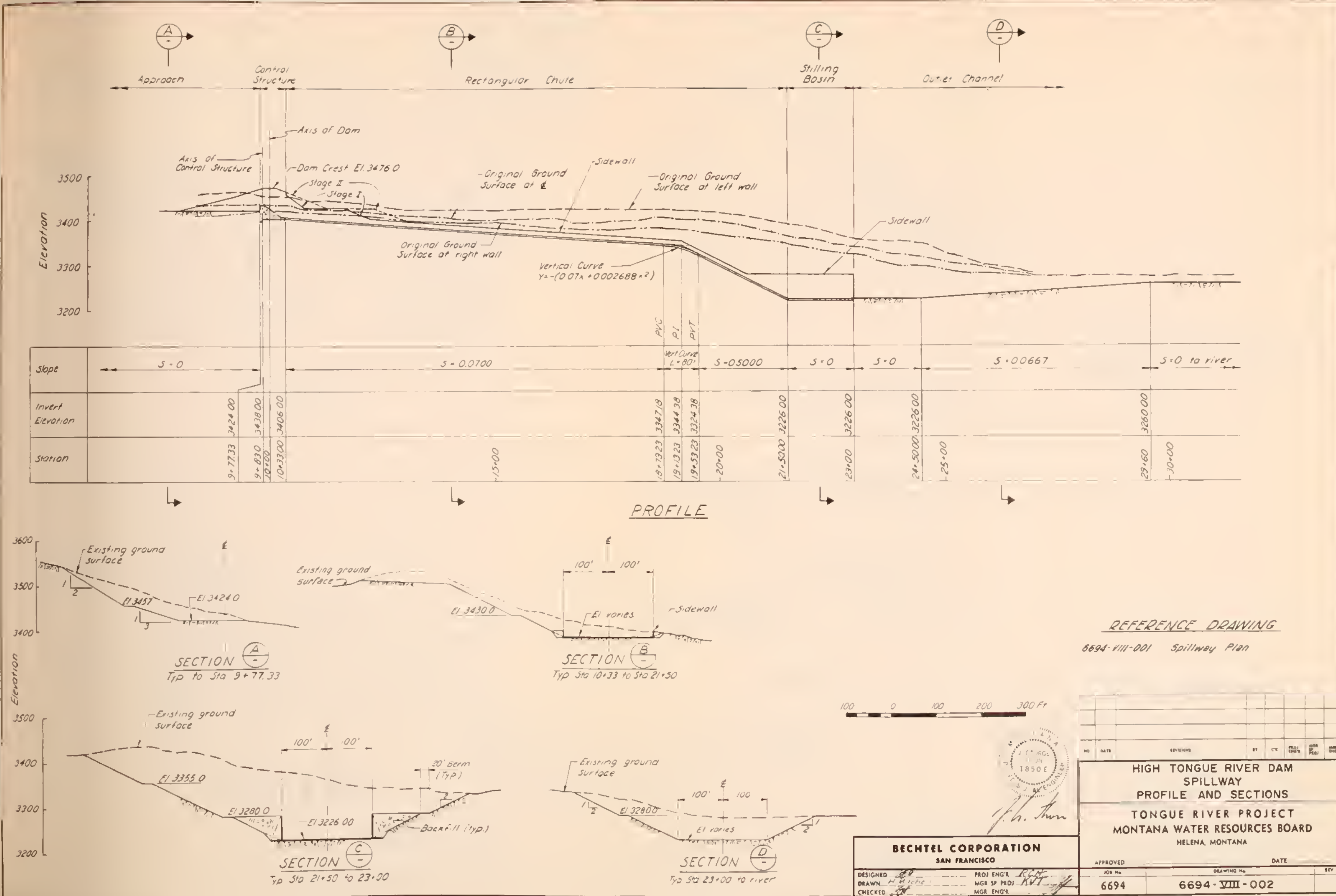
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED / DRAWN / CHECKED — PROJ ENG'R / MGR SP PROJ / MGR ENG'R

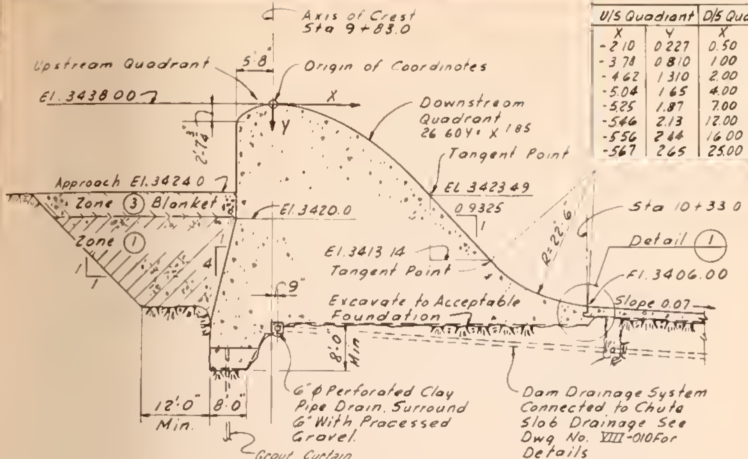
APPROVED ____ DATE ____

JOB No.	DRAWING No.	REV
6694	6694 - VIII - 001	

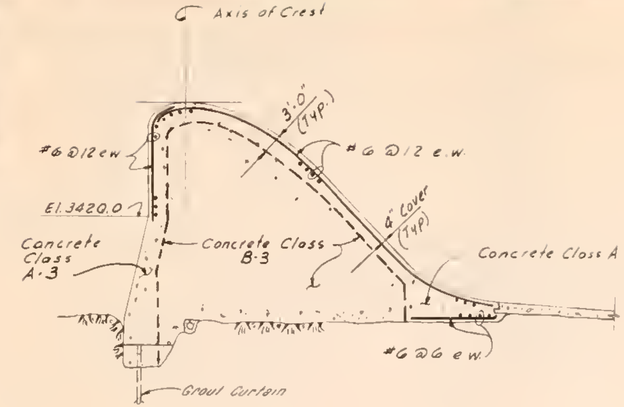

A
B
C
D
Approach
Control Structure
Rectangular Chute
Stilling Basin
Outlet Channel
Axis of Dam
Axis of Control Structure
Dam Crest El. 3476.0
Stage II
Stage I
Original Ground Surface at ℄
Sidewall
Original Ground Surface at left wall
Original Ground Surface at right wall
Vertical Curve Y=-(0.07x+0.002688x²)
Elevation
3500
3400
3300
3200
PVC
PI
PVT
Slope
S=0
S=0.0700
Vert Curve L=80'
S=0.5000
S=0
S=0
S=0.00667
S=0 to river
Invert Elevation
3424.00
3438.00
3406.00
3347.18
3344.38
3324.38
3226.00
3226.00
3226.00
3260.00
Station
9+77.33
9+83.0
10+00
10+33.00
15+00
18+79.23
19+13.23
19+53.23
20+00
21+50.00
23+00
24+50.00
25+00
29+60
30+00
PROFILE
Existing ground surface
El 3457
El 3424.0
SECTION A
Typ to Sta 9+77.33
Existing ground surface
100'
100'
El 3430.0
El varies
Sidewall
SECTION B
Typ Sta 10+33 to Sta 21+50
Existing ground surface
El 3355.0
El 3280.0
El 3226.00
20' Berm (Typ)
Backfill (typ.)
SECTION C
Typ Sta 21+50 to 23+00
Existing ground surface
El 3280.0
El varies
SECTION D
Typ Sta 23+00 to river
REFERENCE DRAWING
6694-VIII-001 Spillway Plan
100 0 100 200 300 Ft
HIGH TONGUE RIVER DAM
SPILLWAY
PROFILE AND SECTIONS
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN
CHECKED
PROJ ENG'R
MGR SP PROJ
MGR ENG'R
APPROVED
DATE
6694
6694-VIII-002

Crest Coordinates

U/S Quadrant		D/S Quadrant	
X	Y	X	Y
-2.10	0.227	0.50	0.014
-3.78	0.810	1.00	0.038
-4.62	1.310	2.00	0.135
-5.04	1.65	4.00	0.489
-5.25	1.87	7.00	1.376
-5.46	2.13	12.00	3.73
-5.56	2.44	16.00	6.35
-5.67	2.65	25.00	14.51



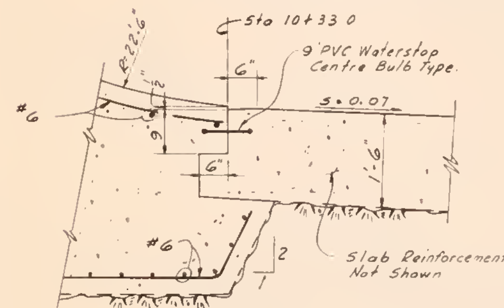
SPILLWAY CREST
GEOMETRY
Scale 1" = 10'-0"



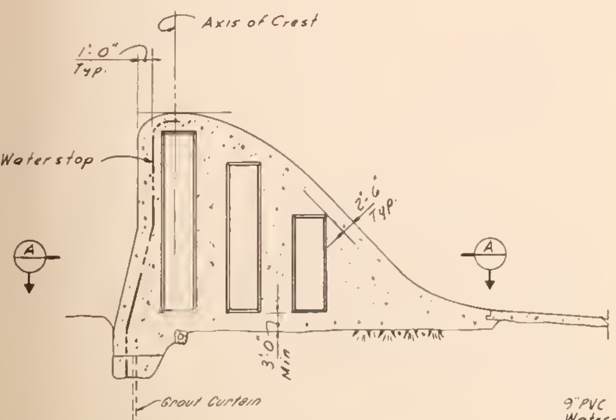
SPILLWAY CREST
TYPICAL REINFORCEMENT & CONCRETE CLASS
Scale 1" = 10'-0"

NOTES

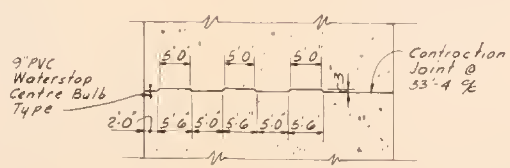
1. Protective cover for reinforcement shall be 3" for concrete placed against the ground.
2. Reinforcement steel splices shall lap 24 bar diameters but not less than 12 inches.



DETAIL 1
Scale 1" = 1'-0"



SPILLWAY CREST
CONTRACTION JOINT
Scale 1" = 10'-0"



SECTION A
Scale 1" = 10'-0"

10 0 10 20 30 40
1 IN. = 10 FT.

1 0 1 2 3 4
1 IN. = 1 FT.

NO	DATE	REVISIONS	BY	CK	PROJ ENGR	MGR SP PROJ	MGR ENGR

HIGH TONGUE RIVER DAM
SPILLWAY
CREST STRUCTURE DETAILS

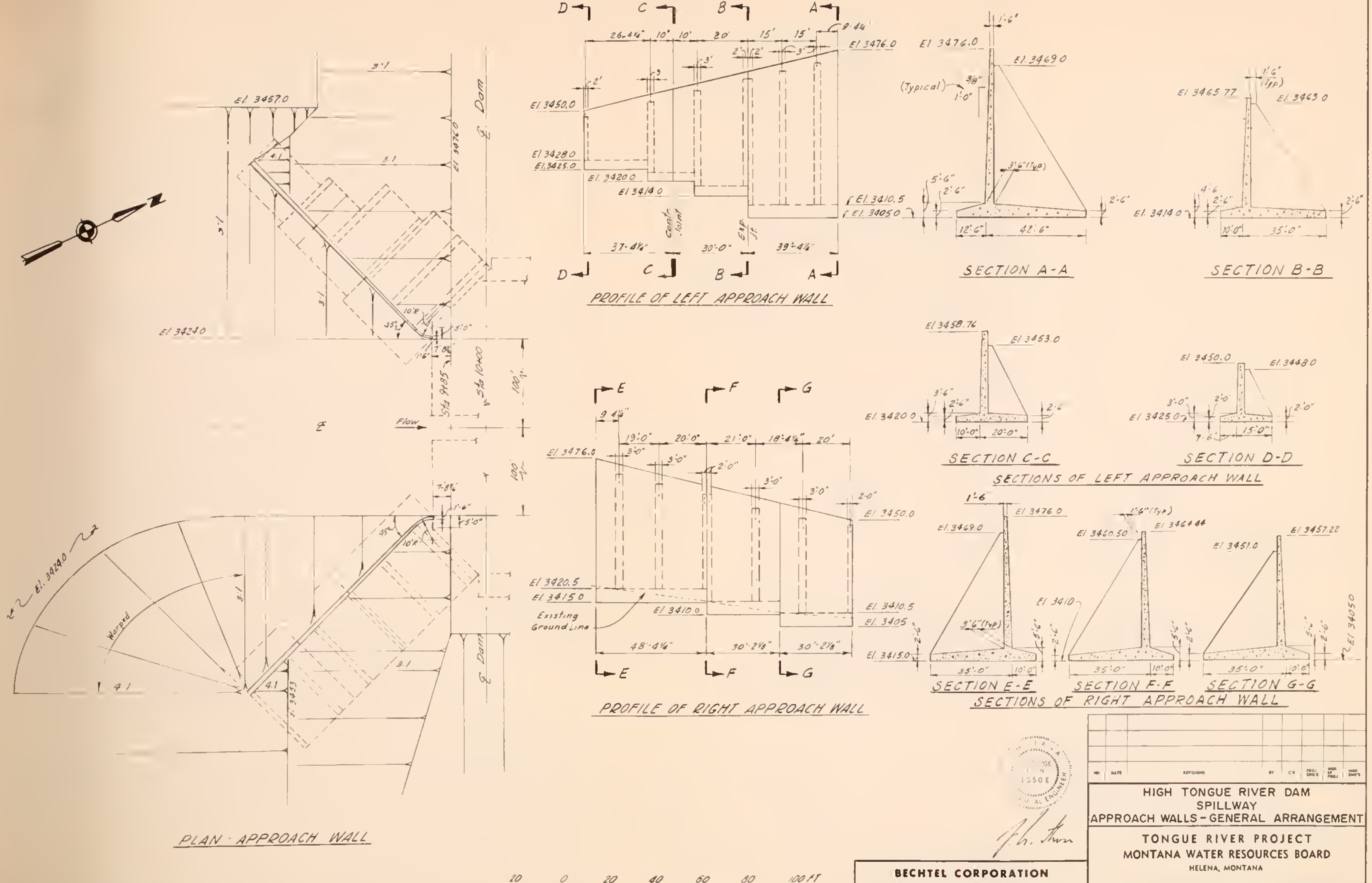
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED RF
DRAWN Mo. leja
CHECKED RF
PROJ ENGR KCH
MGR SP PROJ KVT
MGR ENGR

APPROVED
DATE

JOB No.	DRAWING No.	REV
6694	6694-VIII-003	



HIGH TONGUE RIVER DAM
SPILLWAY
APPROACH WALLS - GENERAL ARRANGEMENT

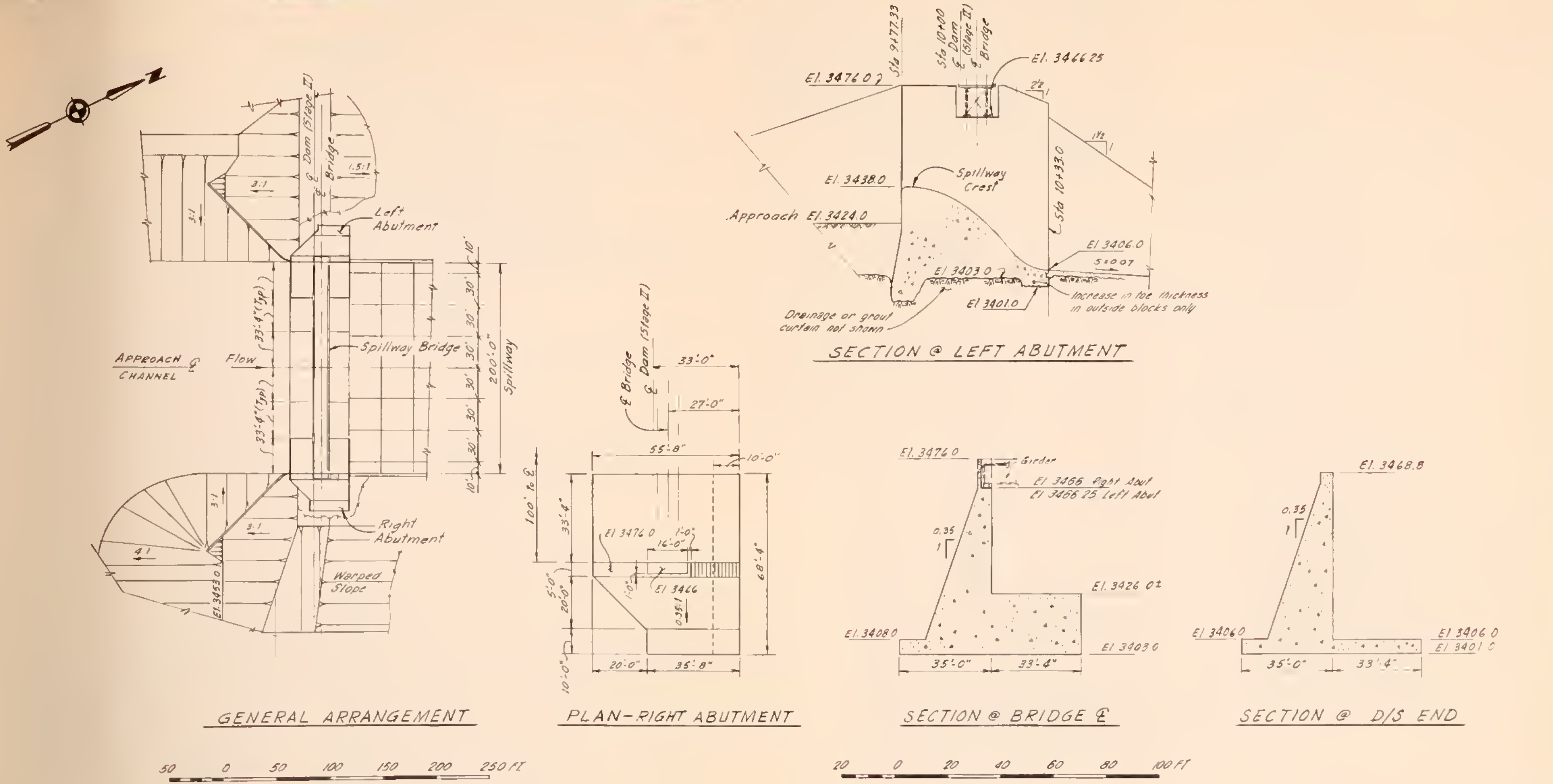
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED	T.R. Dhu	PROJ ENG'R	RGH
DRAWN	L.R.L.	MGR SP PROJ	RVT
CHECKED	T.R. Dhu	MGR ENG'R	

APPROVED ____ DATE ____

JOB No.	DRAWING No.	REV
6694	6694-VIII-004	



NO	DATE	REVISIONS	BY	CK	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
SPILLWAY
CREST WALLS-GENERAL ARRANGEMENT

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED ______ DATE ______

BECHTEL CORPORATION
SAN FRANCISCO

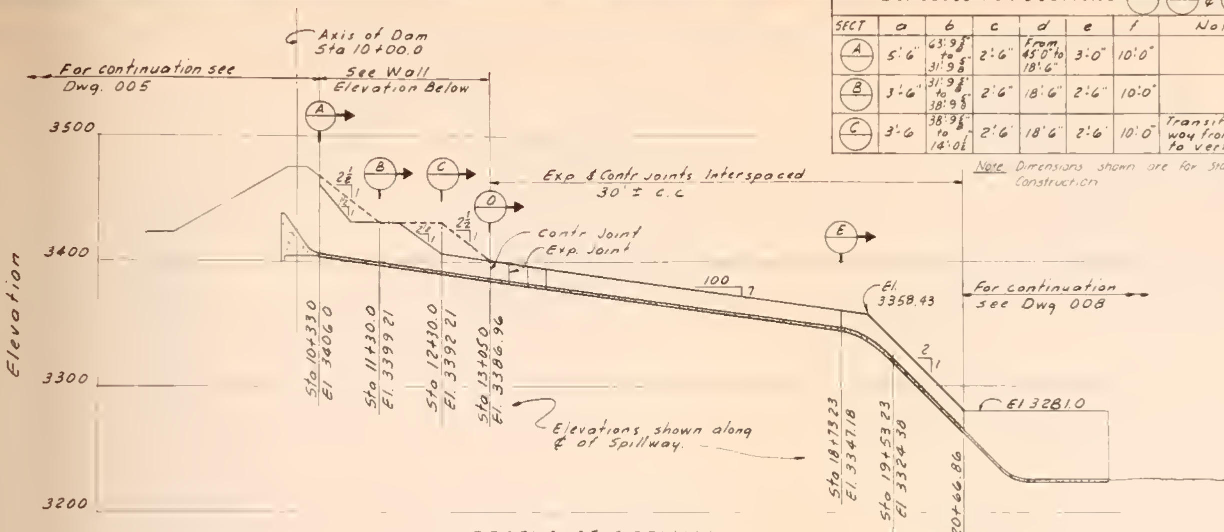
DESIGNED: T.A. Lau — PROJ ENG'R: RCH
DRAWN: J.R.L. — MGR SP PROJ: KVT
CHECKED: T.R. Dh — MGR ENG'R

JOB No	DRAWING No	REV
6694	6694-VIII-005	

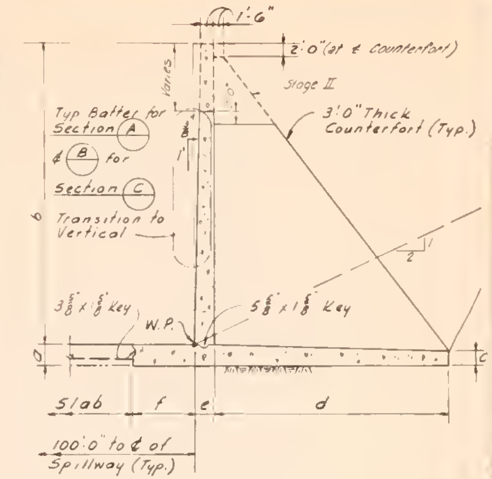
SCHEDULE FOR SECTIONS (A) (B) ¢ (C)

SECT	a	b	c	d	e	f	Notes
A	5'6"	63'9⅝" to 31'9⅝"	2'6"	From 45'0" to 18'6"	3'0"	10'0"	
B	3'6"	31'9⅝" to 38'9⅝"	2'6"	18'6"	2'6"	10'0"	
C	3'6	38'9⅝" to 14'0½	2'6	18'6"	2'6	10'0"	Transition Spillway from typ batter to vertical.

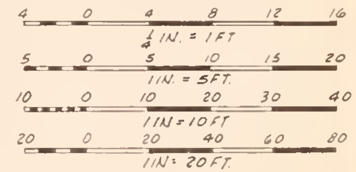
Note: Dimensions shown are for Stage II Construction.

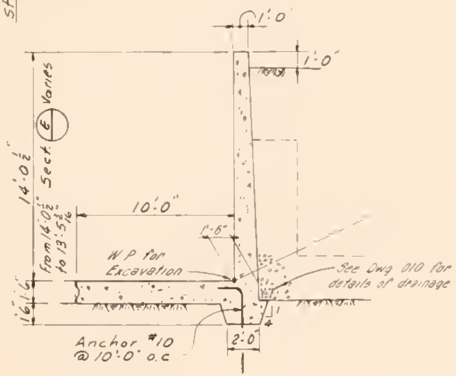


PROFILE OF SIDEWALL
Scale Horiz 1" = 100'-0"
Vert 1" = 50'-0"



SECTIONS (A) (B) ¢ (C)
N.T.S

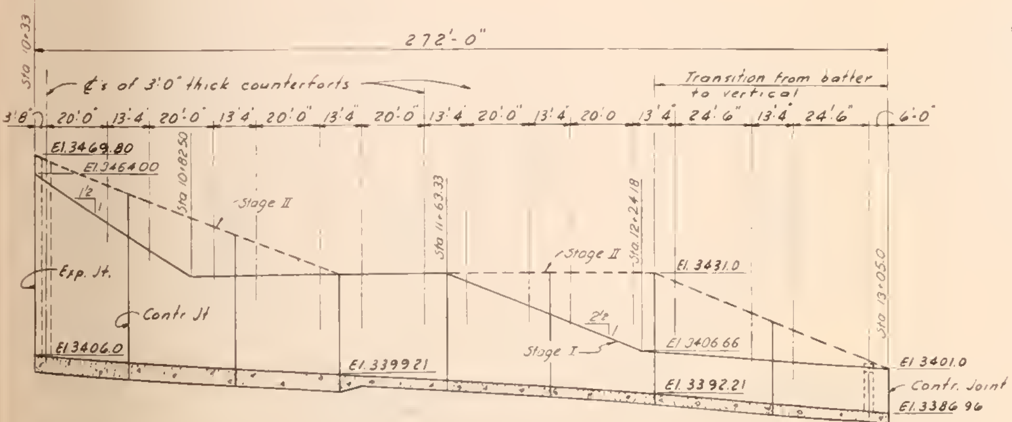




SECTION (D) As Shown

SECTION (E) As Noted

Scale ¼" = 1'-0"



WALL ELEVATION BETWEEN Sta 10+33.0 ¢ Sta. 13+05.0
Scale 1" = 20'-0"

HIGH TONGUE RIVER DAM
SPILLWAY
CHUTE WALLS - DETAILS

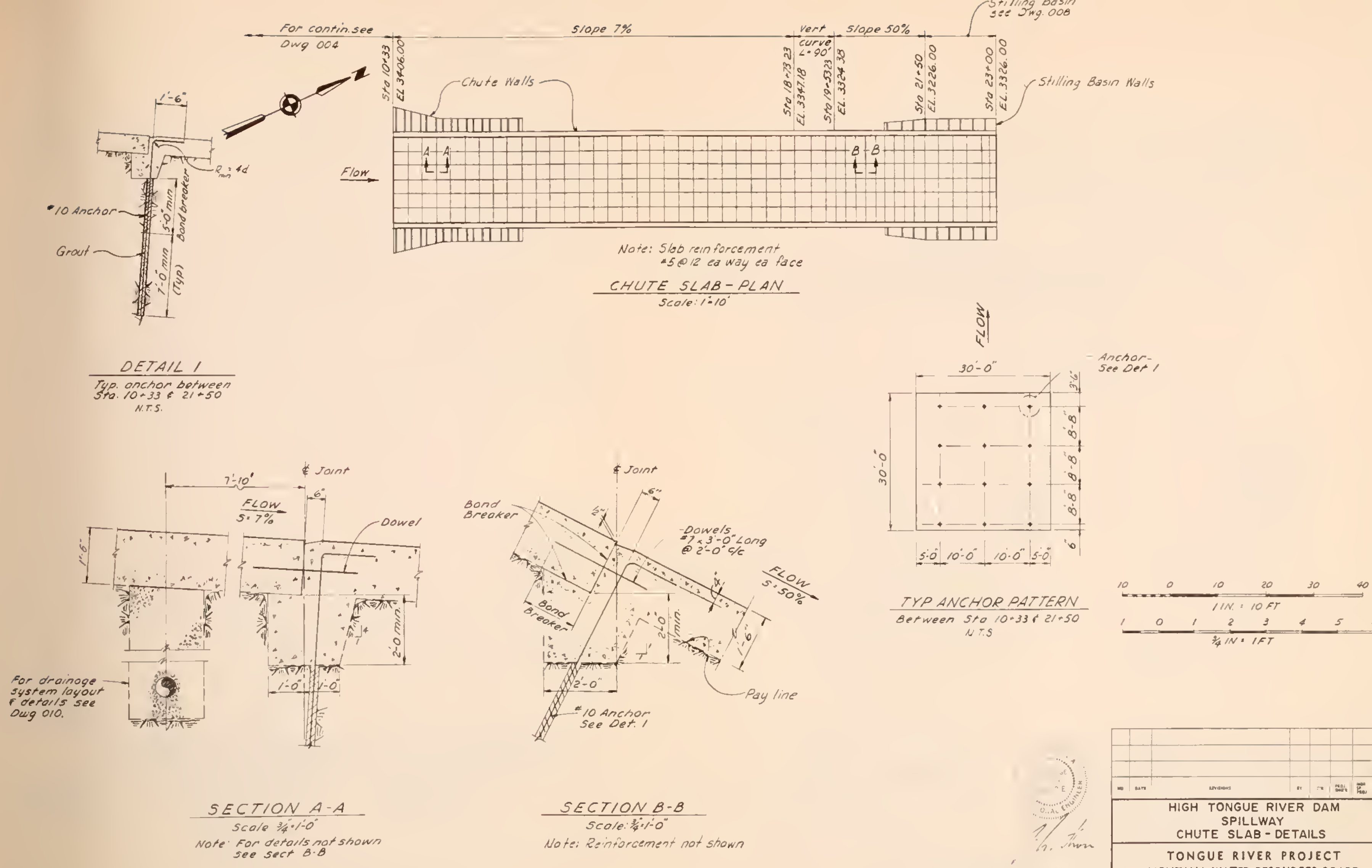
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED ______ DATE ______

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED Salinas — PROJ ENGR RCH
DRAWN Montoya — MGR SP PROJ KVT
CHECKED — MGR ENGR

JOB No.	DRAWING No.	REV
6694	6694 - VIII - 006	



NO	DATE	REVISIONS	BY	CH	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
SPILLWAY
CHUTE SLAB - DETAILS

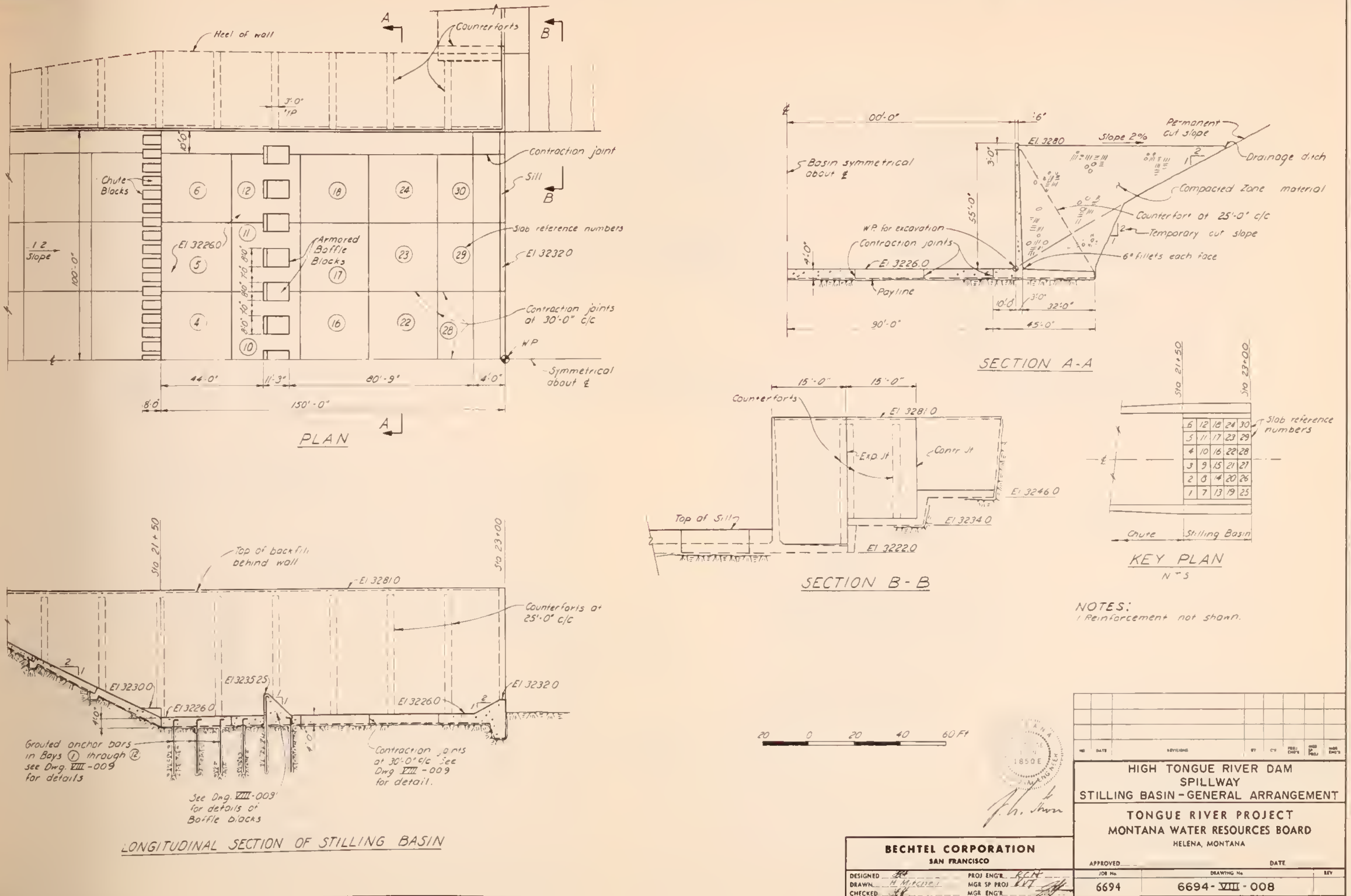
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

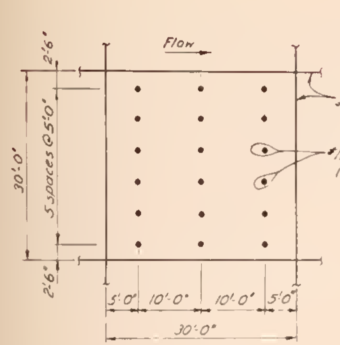
BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED — PROJ ENG'R RCH
DRAWN — MGR SP PROJ KVT
CHECKED — MGR ENG'R

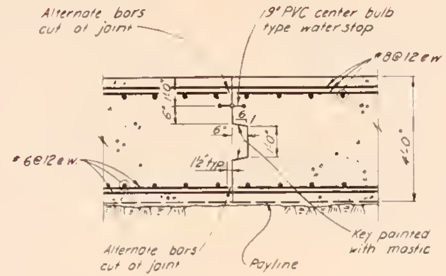
APPROVED — DATE

JOB No.	DRAWING No.	REV
6694	6694 · VIII · 007	

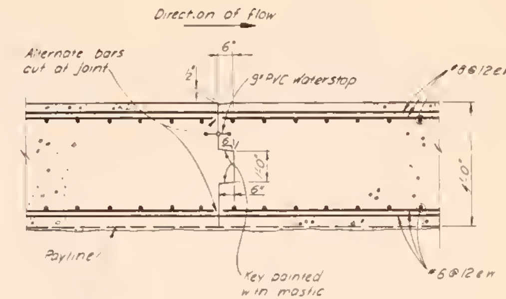

PLAN
Heel of wall
Counterforts
Contraction joint
Chute Blocks
Sill
Slab reference numbers
El 3226.0
El 3232.0
Armored Baffle Blocks
1:2 Slope
100'-0"
Contraction joints at 30'-0" c/c
W.P.
Symmetrical about ℄
44'-0"
11'-3"
80'-9"
4'-0"
8'-0"
150'-0"
SECTION A-A
Basin symmetrical about ℄
El. 3280
Slope 2%
Permanent cut slope
Drainage ditch
Compacted Zone material
Counterfort at 25'-0" c/c
Temporary cut slope
6" fillets each face
W.P. for excavation
Contraction joints
El 3226.0
Payline
90'-0"
45'-0"
32'-0"
55'-0"
SECTION B-B
Counterforts
El 3281.0
Exp Jt
Contr Jt
El 3246.0
El 3234.0
Top of Sill
El 3222.0
15'-0"
KEY PLAN
NTS
Slab reference numbers
Chute
Stilling Basin
Sta 21+50
Sta 23+00
LONGITUDINAL SECTION OF STILLING BASIN
Top of backfill behind wall
El 3281.0
Counterforts at 25'-0" c/c
El 3230.0
El 3226.0
El 3235.25
El 3232.0
Grouted anchor bars in Bays 1 through 12, see Dwg. VIII-009 for details
See Dwg. VIII-009 for details of Baffle blocks
Contraction joints at 30'-0" c/c See Dwg VIII-009 for detail.
NOTES:
1 Reinforcement not shown.
20 0 20 40 60 Ft
HIGH TONGUE RIVER DAM
SPILLWAY
STILLING BASIN - GENERAL ARRANGEMENT
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN
CHECKED
PROJ ENG'R
MGR SP PROJ
MGR ENG'R
APPROVED
DATE
JOB No.
6694
DRAWING No.
6694-VIII-008



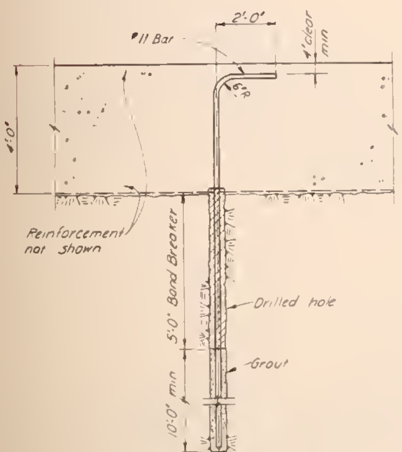
TYPICAL ANCHOR LAYOUT-SLABS 1-12



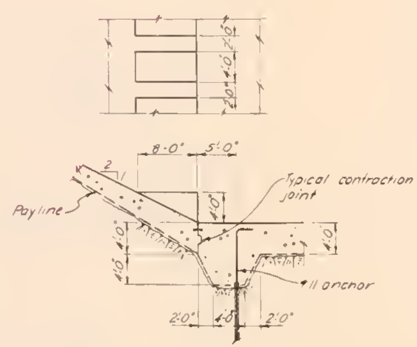
DETAIL OF TYPICAL LONGITUDINAL CONTRACTION JOINT



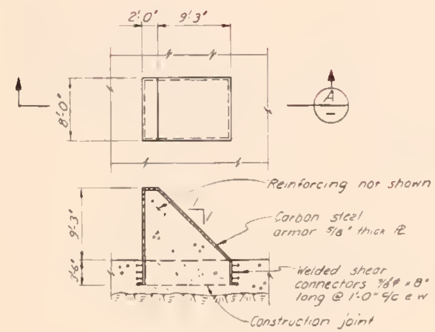
DETAIL OF TYPICAL TRANSVERSE CONTRACTION JOINT



DETAIL OF TYPICAL ANCHOR



DETAIL OF CHUTE BLOCK



SECTION (A)

DETAIL OF BAFFLE BLOCK

NOTES

HIGH TONGUE RIVER DAM
SPILLWAY
STILLING BASIN-DETAILS

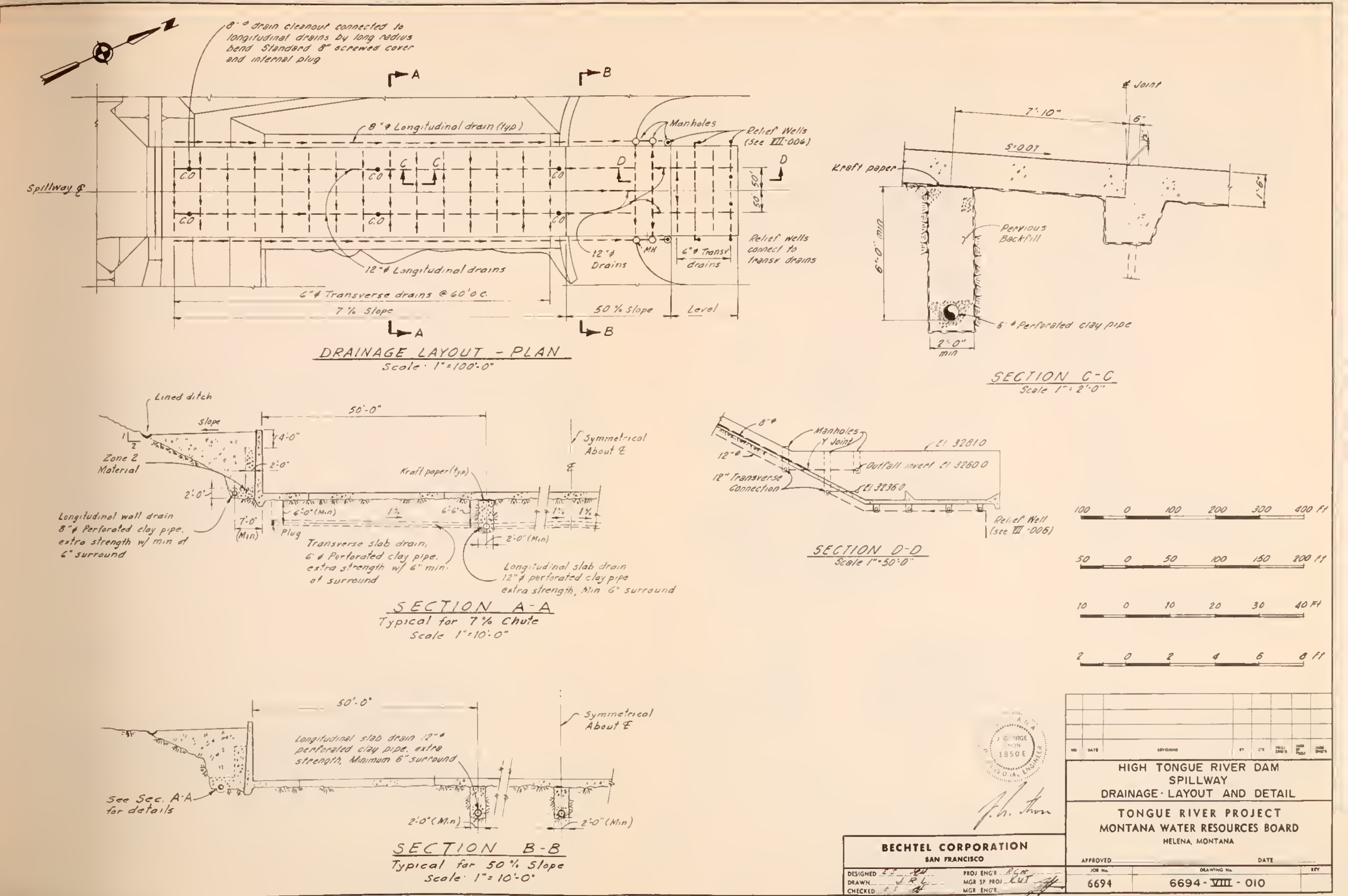
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

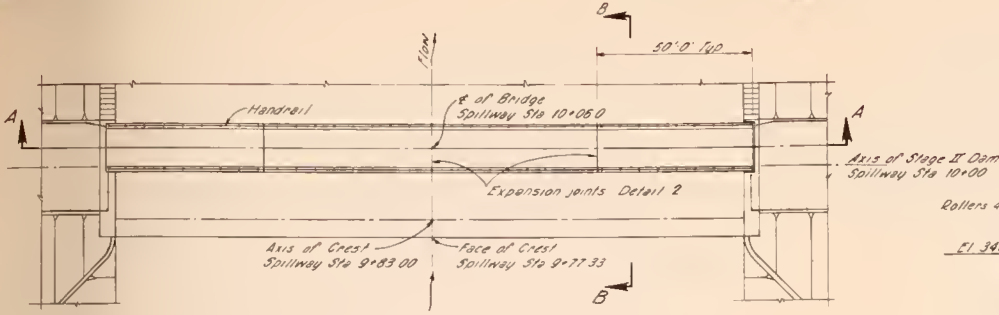
DESIGNED	DRAWN	CHECKED	PROJ ENG'R	MGR SP PROJ	MGR ENG'R
			RCH	KVT	

APPROVED ____ DATE ____

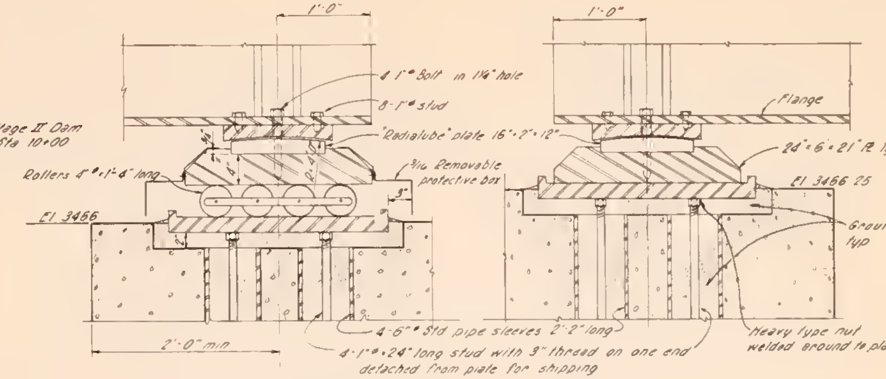
JOB No.	DRAWING No.	REV
6694	6694-VIII-009	



8" ϕ drain cleanout connected to longitudinal drains by long radius bend Standard 8" screwed cover and internal plug
A
B
8" ϕ Longitudinal drain (typ)
Manholes
Relief Wells (See VII-006)
Spillway ℄
C.O
C
D
50'
MH
12" ϕ Drains
6" ϕ Transv drains
Relief wells connect to transv drains
12" ϕ Longitudinal drains
6" ϕ Transverse drains @ 60' o.c.
7% Slope
50% Slope
Level
DRAINAGE LAYOUT - PLAN
Scale 1" = 100'-0"
℄ Joint
7'-10"
6"
5:001
Kraft paper
Pervious Backfill
6'-0" min
1'-6"
6" ϕ Perforated clay pipe
2'-0" min
SECTION C-C
Scale 1" = 2'-0"
Lined ditch
Slope
50'-0"
4'-0"
2'-0"
Symmetrical About ℄
Zone 2 Material
Kraft paper (typ)
6'-0" (Min)
1%
6'-6"
7'-0" (Min)
Plug
Longitudinal wall drain 8" ϕ Perforated clay pipe, extra strength w/ min of 6" surround
Transverse slab drain, 6" ϕ Perforated clay pipe, extra strength w/ 6" min of surround
2'-0" (Min)
Longitudinal slab drain 12" ϕ perforated clay pipe extra strength, Min 6" surround
SECTION A-A
Typical for 7% Chute
Scale 1" = 10'-0"
8" ϕ
Manholes
Y Joint
El 3281.0
12" ϕ
Outfall invert El 3260.0
12" Transverse Connection
El 3236.0
Relief Well (see VII-006)
SECTION D-D
Scale 1" = 50'-0"
100 0 100 200 300 400 Ft
50 0 50 100 150 200 Ft
10 0 10 20 30 40 Ft
2 0 2 4 6 8 Ft
50'-0"
Symmetrical About ℄
Longitudinal slab drain 12" ϕ perforated clay pipe, extra strength, Minimum 6" surround
See Sec. A-A for details
2'-0" (Min)
SECTION B-B
Typical for 50% Slope
Scale 1" = 10'-0"
NO. DATE REVISIONS
HIGH TONGUE RIVER DAM
SPILLWAY
DRAINAGE - LAYOUT AND DETAIL
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN J.R.L.
CHECKED
PROJ ENGR
MGR SP PROJ
MGR ENGR
APPROVED
DATE
JOB No. 6694
DRAWING No. 6694-VIII-010



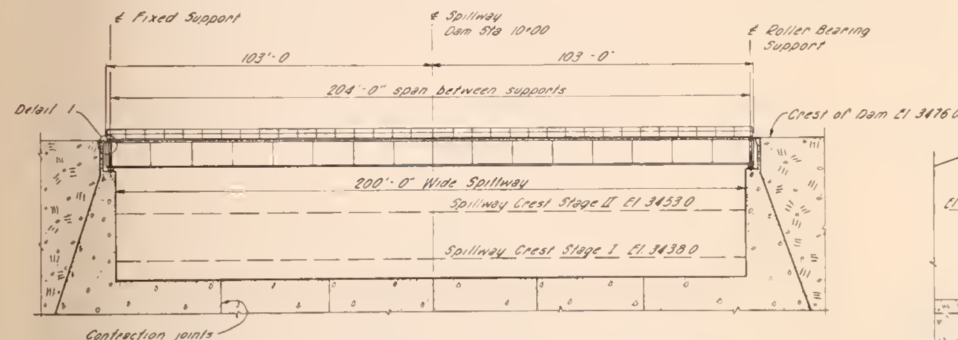
PLAN



ROLLER BEARING FIXED

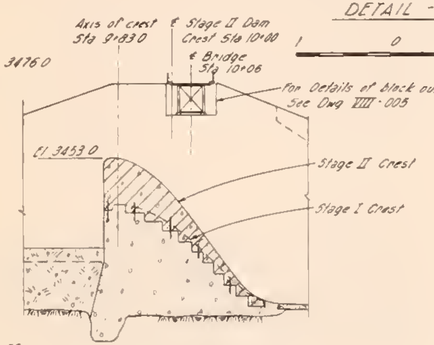
DETAIL - BRIDGE SUPPORT

1 0 1 2 3 FT



SECTION A-A

20 0 20 40 60 80 100 FT



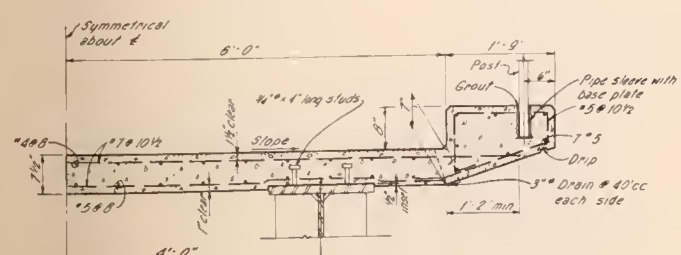
SECTION B-B

NOTES

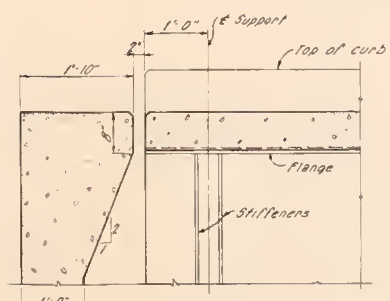
1. Design loading for the bridge is AASHO H-20-44
2. Concrete shall be class A-1½
3. All permanently exposed corners shall be chamfered ¾" unless otherwise shown
4. Splices in reinforcement shall be lapped a minimum of 24 bar diameters

REFERENCE DRAWINGS

6694-VIII-005 Spillway-Crest Wall-General Arrangement

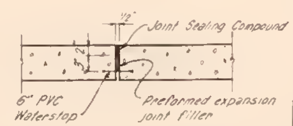


DETAIL - BRIDGE DECK



DETAIL 1

1 0 1 2 3 4 5 FT



DETAIL 2

NO	DATE	REVISIONS	BY	CK	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
SPILLWAY
BRIDGE-GENERAL ARRANGEMENT

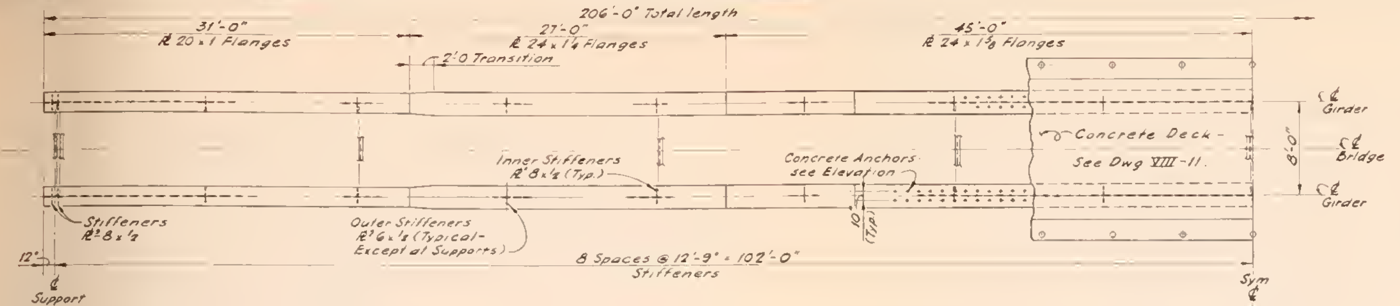
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED ______ DATE ______

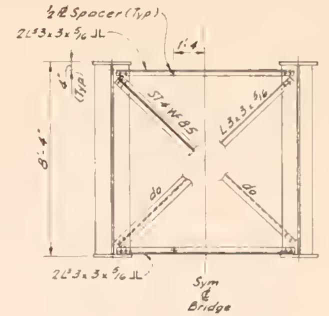
BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED | PROJ ENG'R
DRAWN SHIMAURA | MGR SP PROJ
CHECKED | MGR ENG'R

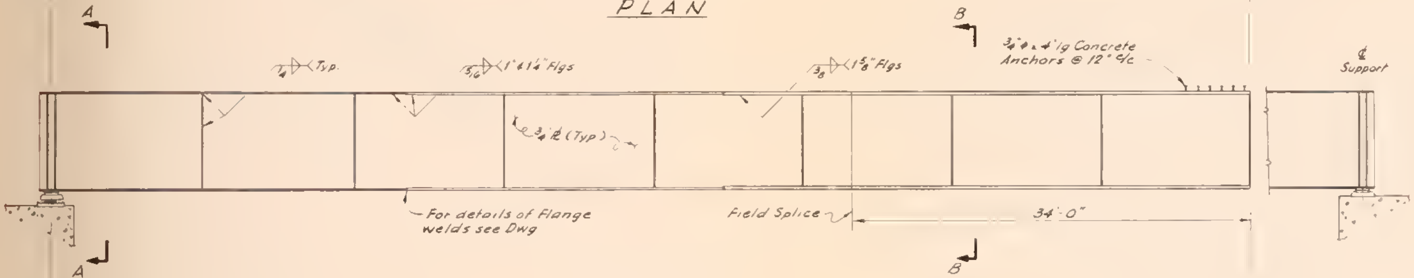
JOB No	DRAWING No	REV
6694	6694-VIII-011	



PLAN



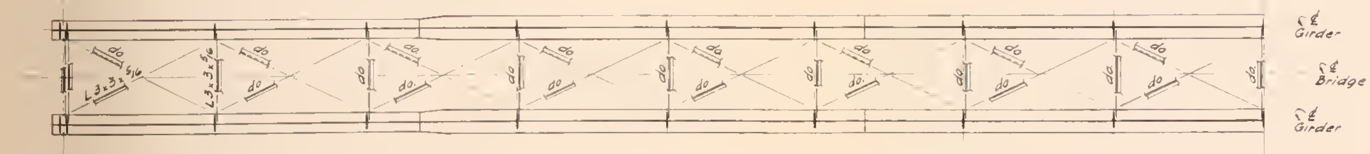
SECTION A-A SECTION B-B



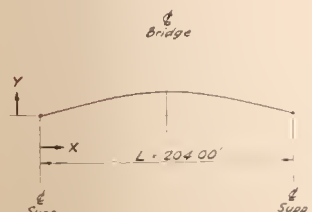
ELEVATION

NOTES

1. Structural steel shall be Cor-Ten B, high-strength low alloy steel conforming to ASTM Spec A 588, Grade A
2. Bolts shall be cadmium plated bearing type, conforming to ASTM Spec A 325



PLAN OF BOTTOM CHORD



X	Y	X	Y
5.10'	1.17"	56.10	9.57"
10.20'	2.28"	61.20'	10.08"
15.30'	3.33"	66.30'	10.53"
20.40'	4.32"	71.40'	10.92"
25.50'	5.25"	76.50'	11.25"
30.60'	6.12"	81.60'	11.52"
35.70'	6.93"	86.70'	11.73"
40.80'	7.68"	91.80'	11.88"
45.90'	8.37"	96.90'	11.97"
51.00	9.00"	102.00'	12.00"

CAMBER DIAGRAM

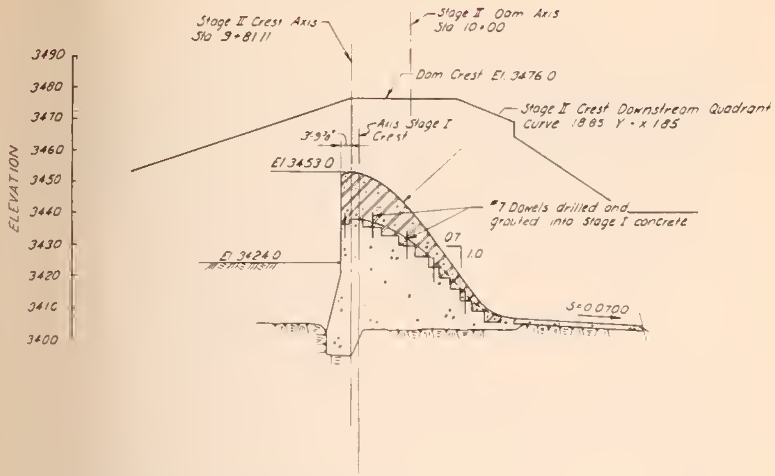
HIGH TONGUE RIVER DAM
SPILLWAY
BRIDGE - STRUCTURAL STEEL DETAILS

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

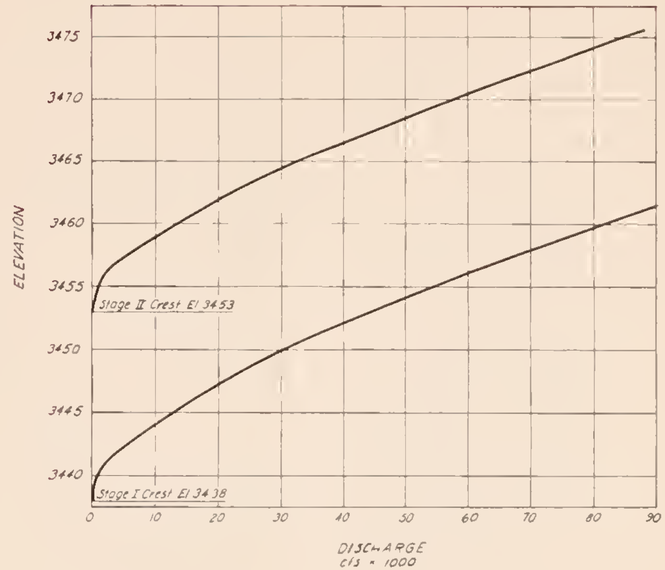
DESIGNED
DRAWN R. ZWEIFEL
CHECKED
PROJ ENG'R
MGR SP PROJ
MGR ENG'R
APPROVED
DATE

JOB No 6694
DRAWING No 6694-VIII-012



TYPICAL SECTION OF
RAISED SPILLWAY CREST

20 0 20 40 60 Ft



SPILLWAY RATING CURVE

NO	DATE	REVISIONS	BY	CK	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

HIGH TONGUE RIVER DAM
SPILLWAY
RATING CURVE AND STAGE II CREST

TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED ______ DATE ______

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED ___ PROJ ENG'R RCH
DRAWN Mitchell MGR SP PROJ KVT
CHECKED ___ MGR ENG'R ___

JOB No.	DRAWING No.	REV
6694	6694-VIII-013	

IX. OUTLET WORKS

GENERAL

The outlet works are located in a trench through the low terrace on the left side of the river channel. General arrangement is shown on Drawing IX-001. The full length of the outlet works required for Stage II construction will be constructed to Stage I because of the great difficulty in moving the outlet structure downstream. The required capacity of the outlet works is based on two considerations: delivery criteria and capability to lower the storage pool.

The delivery criteria, based on minimum pool elevation 3310 are:

Industrial use	100 cfs
Prior adjudicated rights and allowance for reserved Indian lands	342
Existing Agricultural Contracts	133
Total	575 cfs

The delivery criteria would require a capacity to deliver 34,500 acre feet in any 30 day period.

It is judged that the outlet works should have sufficient capacity to release about one third of the second stage storage in 30 days. This amounts to reducing storage by about 150,000 acre feet in 30 days, which requires a discharge of 2500 cfs in excess of inflow. Except during the months of May and June, inflow is less than 500 cfs. Therefore the required design discharge has been established at 3000 cfs.

The outlet works are designed to meet the 3000 cfs discharge when the reservoir water surface is at elevation 3438. The outlet works capacity at minimum pool elevation 3310 is 1200 cfs. The elevation of the outlet valve centerline was set at 3280 to prevent submergence of the valve during spillway discharge. The plan and profile of the outlet works are shown on Dwg. 6694-IX-001.

HYDRAULIC DESIGN

Outlet works hydraulics were computed on the basis of the following head losses:

Trashrack	$0.38\ V^2/2g$
Entrance (bellmouth)	$0.05\ V^2/2g$
Contractions	$0.10\ (V_2-V_1)^2/2g$
Expansion (12 Degrees)	$0.10\ (V_1-V_2)^2/2g$
Butterfly Valve	$0.40\ V^2/2g$
Fixed Cone Valve	$0.41\ V^2/2g$
Friction-Steel Lined Conduit-Mannings	"n" = 0.012
Exit	$1.0\ V^2/2g$

The hydraulic design also included a study of the gates and valves provided for flow regulation and control.

At the upstream end of the conduit, a guard gate has been provided for emergency closure of the outlet works. This gate will be lowered from a barge by a diver, into slots in the intake structure.

A 108 inch diameter, hydraulically operated butterfly valve is located in the conduit. This valve is designed for 190 feet of head and for emergency closure in the event of failure of the downstream regulating valve. Closure time of the butterfly valve under emergency conditions will be controlled at 6 minutes to reduce the undesirable effects of rapid closure. Admission of air into the conduit after emergency closure will be provided by 7 - 10 inch diameter air inlet valves. One valve will be located immediately downstream of the butterfly valve and thereafter at 25 ft spacing.

At the downstream end of the conduit a 90 inch diameter, electrically operated, fixed cone dispersion valve is provided for regulation of outlet works discharges. Design of the outlet works is such that hydraulic control is at the downstream regulating valve under all conditions of flow.

STRUCTURAL DESIGN

The 10 foot diameter outlet works conduit is steel lined throughout. A 15 foot wide by 15 foot deep trench is excavated in bedrock and the space between the conduit and the trench filled with structural concrete, thus saving forming costs. The steel conduit is provided with external welded stud anchors to develop shell stiffening action with the concrete surround. The steel conduit is designed to resist the full reservoir head plus full internal vacuum as an external load.

The intake structure incorporates trashracks, a bellmouth transition and slots for the guard gate. The intake structure is shown on Dwg.6694-IX-002.

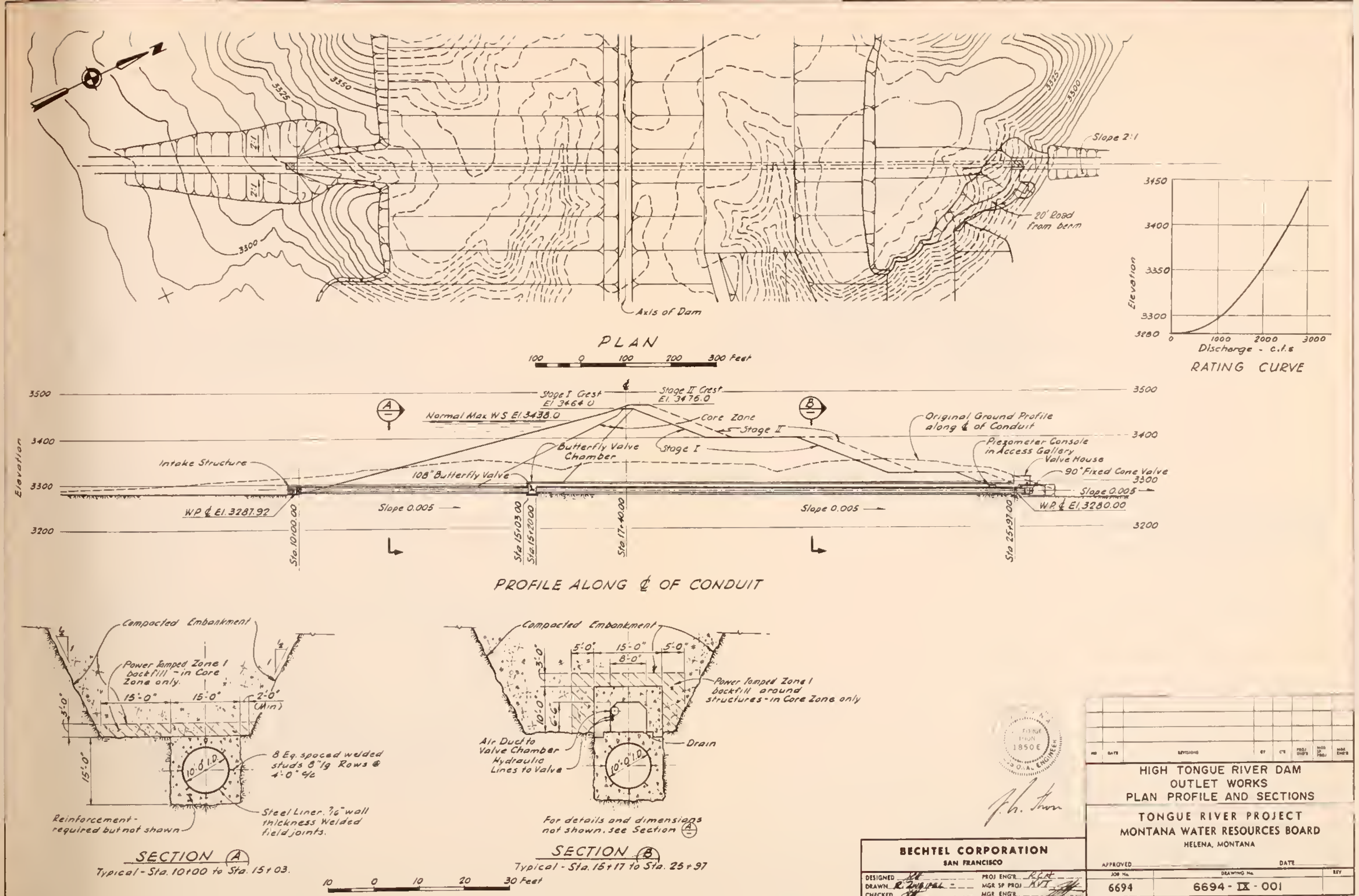
The 108 inch diameter butterfly is housed in a chamber located in the impervious zone, foundation contact. The valve and chamber are shown on Dwg. No. 6694-IX-003.

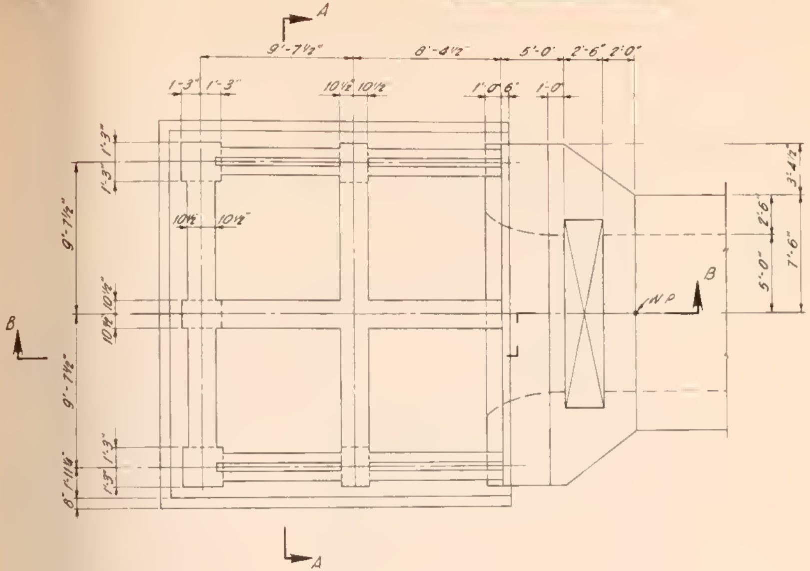
Provision is made for withdrawal of industrial water by a 4-foot diameter tee located immediately upstream of the regulating valve. Initially the tee is capped with a blind flange.

A control building is located on top of the regulating valve structure. From this building, a six and one half foot high by eight foot wide manway provides access to the butterfly valve chamber. Piezometer gauges housed in an insulated and heated box are located near the downstream end of the manway. The outlet structure is shown on Drawing No. 6694-IX-004.

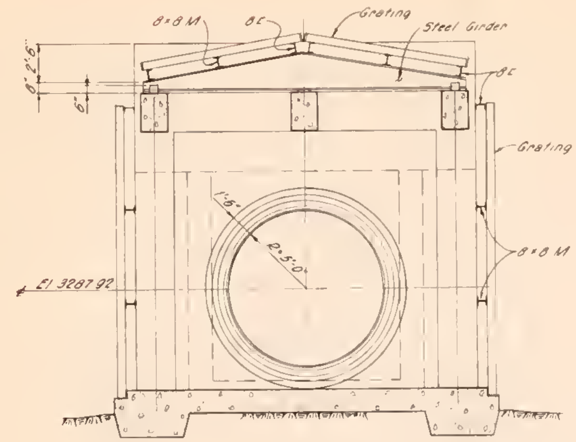
The conduit downstream of the butterfly valve may be dewatered and manholes have been provided for inspection of the conduit interior.

Circulation of air between the outside and the valve chamber has been provided through the air demand of the fixed cone dispersion valve.

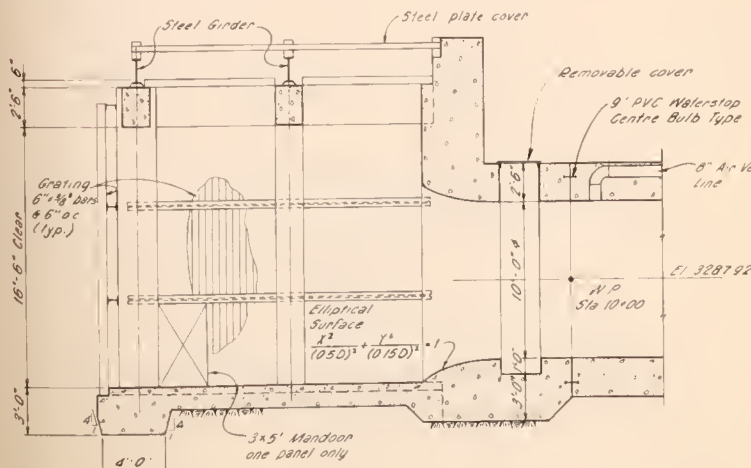

3350
3325
3300
2:1
Axis of Dam
Slope 2:1
20' Road from berm
PLAN
100 0 100 200 300 Feet
3450
3400
3350
3300
3280
Elevation
0 1000 2000 3000
Discharge - c.f.s
RATING CURVE
Stage I Crest El. 3464.0
Stage II Crest El. 3476.0
Normal Max W.S. El. 3438.0
Core Zone
Stage II
Stage I
Original Ground Profile along ℄ of Conduit
Piezometer Console in Access Gallery
Valve House
90° Fixed Cone Valve
Intake Structure
Butterfly Valve Chamber
108" Butterfly Valve
Slope 0.005
W.P. ℄ El. 3287.92
W.P. ℄ El. 3280.00
Sta. 10+00.00
Sta. 15+03.00
Sta. 15+20.00
Sta. 17+40.00
Sta. 25+97.00
3500
3400
3300
3200
Elevation
PROFILE ALONG ℄ OF CONDUIT
Compacted Embankment
Power Tamped Zone I backfill - in Core Zone only
15'-0" 15'-0" 2'-0" (Min)
3'-0"
15'-0"
10'-0" I.D.
8 Eq. spaced welded studs 8" lg Rows @ 4'-0" c/c
Reinforcement - required but not shown
Steel Liner. 7/16" wall thickness Welded field joints.
SECTION A
Typical - Sta. 10+00 to Sta. 15+03.
Compacted Embankment
5'-0" 15'-0" 5'-0"
8'-0"
3'-0"
10'-0"
6'-6"
Power Tamped Zone I backfill around structures - in Core Zone only
Air Duct to Valve Chamber
Hydraulic Lines to Valve
Drain
10'-0" I.D.
For details and dimensions not shown, see Section A
SECTION B
Typical - Sta. 15+17 to Sta. 25+97
10 0 10 20 30 Feet
1850E
HIGH TONGUE RIVER DAM
OUTLET WORKS
PLAN PROFILE AND SECTIONS
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN
CHECKED
PROJ ENG'R
MGR SP PROJ
MGR ENG'R
APPROVED
DATE
JOB No.
DRAWING No.
REV
6694
6694 - IX - 001



ROOF PLAN



SECTION A-A



SECTION B-B

4 0 4 8 12 16 20 FT.

NOTES

A bulkhead gate fabricated from structural steel will be provided for emergency closure of the conduit. The gate will be stored at the left abutment of the dam.

NO	DATE	REVISIONS	BY	CK	PROJ ENG'R	MGR SP PROJ	MGR ENG'R

BECHTEL CORPORATION
SAN FRANCISCO

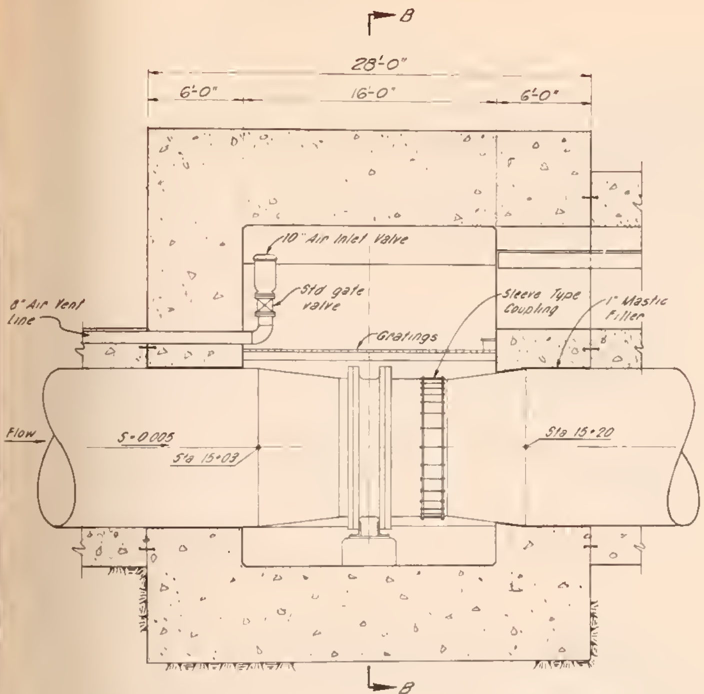
DESIGNED E.S.
DRAWN SHIMAURA
CHECKED
PROJ ENG'R B.G.H.
MGR SP PROJ K.V.T.
MGR ENG'R

HIGH TONGUE RIVER DAM
OUTLET WORKS
INTAKE STRUCTURE - CONCRETE OUTLINE

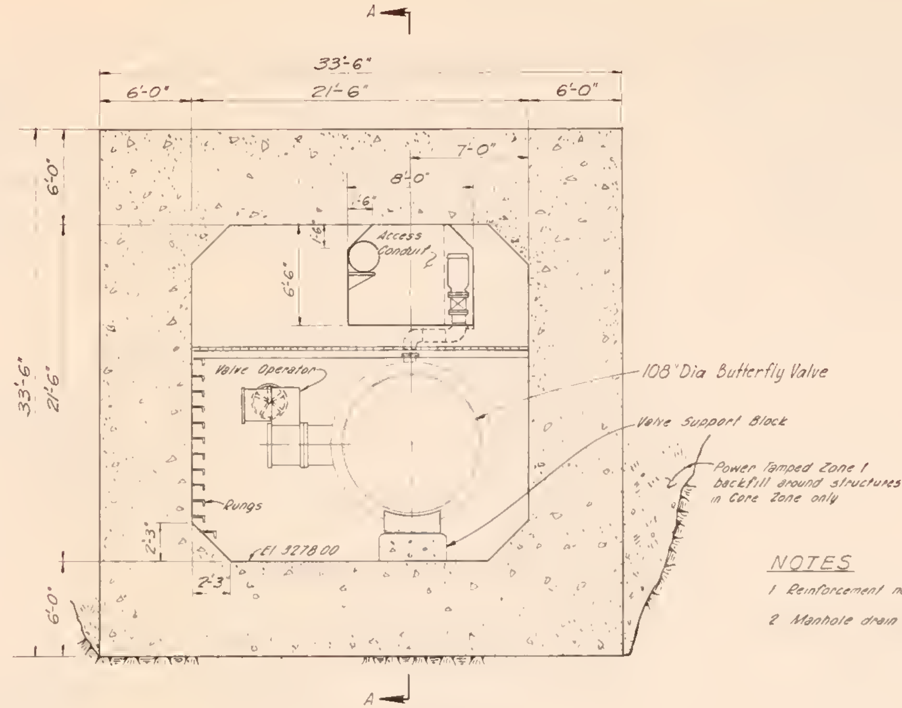
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

APPROVED
DATE

JOB No.	DRAWING No.	REV
6694	6694-IX-002	



LONGITUDINAL SECTION A-A



SECTION B-B

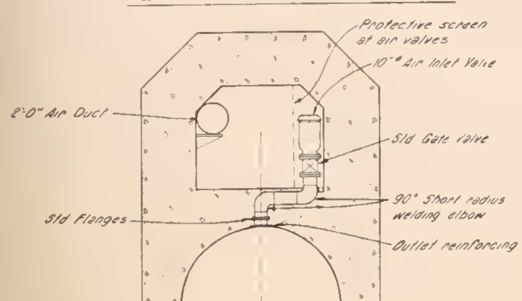
NOTES

1 Reinforcement not shown

2 Manhole drain line and auxiliary piping not shown

REFERENCE DRAWINGS

6694-II-001 Outlet Works - Plan, Profile and Sections



TYPICAL AIR VALVE

7 valves @ 25'-0" centers
First valve ⊈ Sta 15+22

4 0 4 8 12 16 20 FT

HIGH TONGUE RIVER DAM
OUTLET WORKS
VALVE CHAMBER — CONCRETE OUTLINE

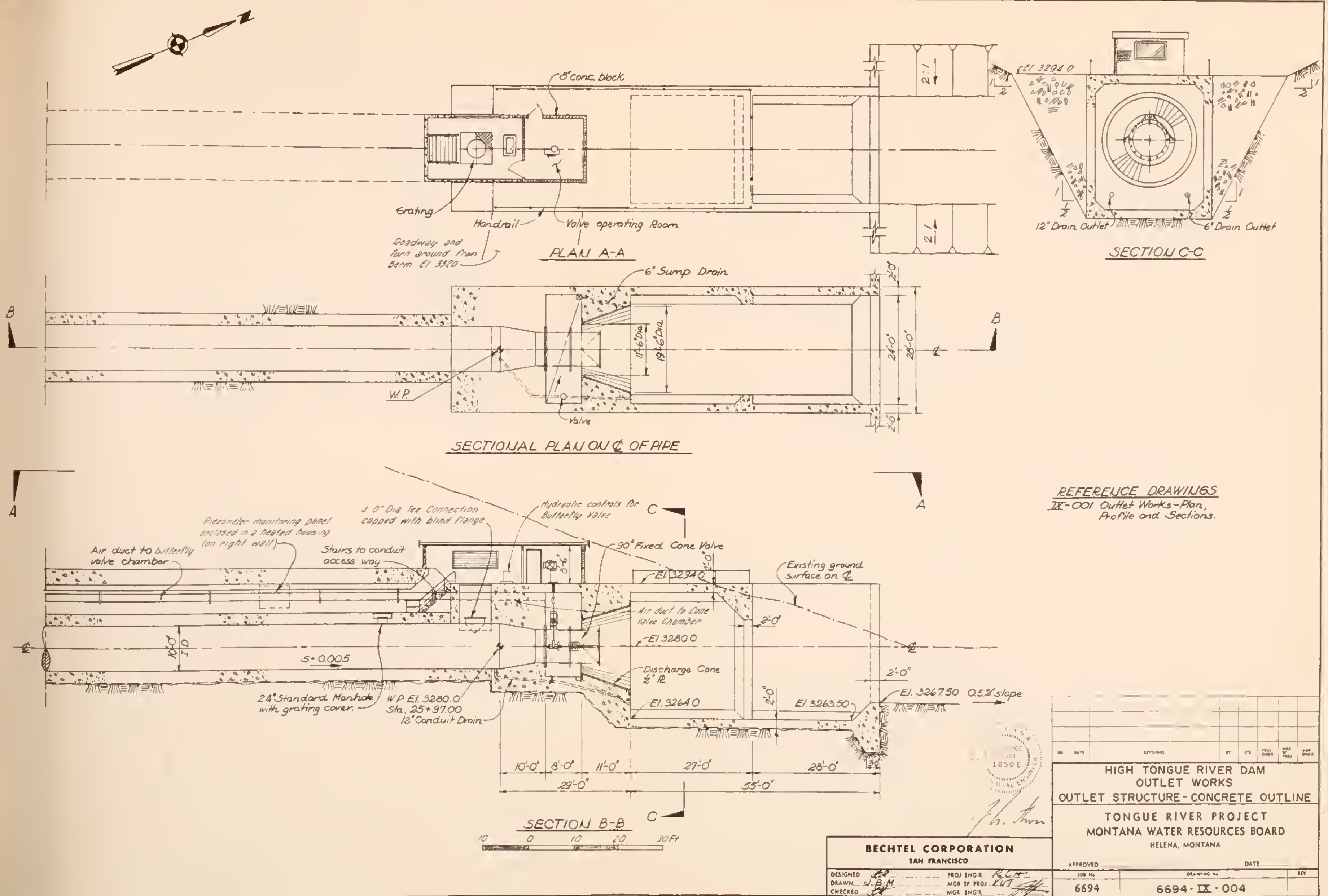
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA

BECHTEL CORPORATION
SAN FRANCISCO

DESIGNED | DRAWN MKM | CHECKED | PROJ ENGR | MGR SP PROJ | MGR ENGR

APPROVED | DATE

JOB No. 6694 | DRAWING No. 6694-IX-003



8" conc. block
Grating
Handrail
Valve operating Room
Roadway and Turn around from Berm El 3320
PLAN A-A
El 3294.0
12" Drain Outlet
6" Drain Outlet
SECTION C-C
6" Sump Drain
11'-6" Dia
19'-6" Dia
24'-0"
28'-0"
2'-0"
W.P.
Valve
SECTIONAL PLAN ON ℄ OF PIPE
REFERENCE DRAWINGS
IX-001 Outlet Works-Plan, Profile and Sections.
Piezometer monitoring panel enclosed in a heated housing (on right wall)
4'-0" Dia Tee Connection capped with blind flange
Hydraulic controls for Butterfly Valve
Air duct to butterfly valve chamber
Stairs to conduit access way
90° Fixed Cone Valve
Existing ground surface on ℄
El. 3294.0
Air duct to Cone Valve Chamber
El 3280.0
Discharge Cone ½" R
El. 3264.0
El. 3263.50
El. 3267.50 0.5% slope
S=0.005
10'-0" I.D.
24" Standard Manhole with grating cover.
W.P. El. 3280.0 Sta. 25+97.00
12" Conduit Drain
10'-0" 8'-0" 11'-0" 27'-0" 28'-0"
29'-0" 55'-0"
SECTION B-B
10 0 10 20 30 Ft
HIGH TONGUE RIVER DAM
OUTLET WORKS
OUTLET STRUCTURE - CONCRETE OUTLINE
TONGUE RIVER PROJECT
MONTANA WATER RESOURCES BOARD
HELENA, MONTANA
BECHTEL CORPORATION
SAN FRANCISCO
DESIGNED
DRAWN J.B.M.
CHECKED
PROJ ENGR
MGR SP PROJ
MGR ENG'R
APPROVED
DATE
JOB No.
6694
DRAWING No.
6694-IX-004

X. COST ESTIMATE

An order-of-magnitude estimate of the project cost for Stage 1 development has been prepared. This estimate is based on quantities for the major items of work calculated from the drawings presented in this report. The estimate considers three construction seasons will be required. The Specific Construction Cost corresponds to a construction contractor's bid, presented at a 4th Quarter, 1968, price level. Those items of project cost which can be estimated at this time are added to the Specific Construction Cost; contingencies, engineering, management of construction and part of the anticipated cost escalation. The 15% allowed for cost escalation covers the period from an undefined project release date through one year of pre-construction engineering and three years of construction. Excluded from the estimated Total Project Cost are those items which are to be determined by the Montana Water Resources Board after financing arrangements and the project schedule become known. These excluded items are the cost of land and rights of way, engineering costs already incurred, escalation from the present to the date of project release, financing costs and other client costs. In considering financing costs, it should be noted that interest on borrowed capital during reservoir filling is a significant item, since the time which must be allowed for reservoir filling is four to six years.

TONGUE RIVER PROJECT

HIGH TONGUE RIVER DAM

FOUR MILE SITE--CREST ELEVATION 3464

ORDER-OF-MAGNITUDE COST ESTIMATE

LAND AND LAND RIGHTS	(See Note)
RESERVOIR	$ 35,000
EARTHFILL DAM	12,824,000
SPILLWAY	6,968,000
OUTLET WORKS	2,256,000
SITE IMPROVEMENTS	50,000
SUBTOTAL, SPECIFIC CONSTRUCTION COST, 4th Quarter, 1968, Price Level	$22,133,000
ALLOWANCE FOR CONTINGENCIES	3,755,000
ENGINEERING	
To Date	Not Included
Pre Construction	422,000
During Construction	315,000
MANAGEMENT OF CONSTRUCTION	1,400,000
SUBTOTAL	28,025,000
ALLOWANCE FOR COST ESCALATION	
4th Quarter, 1968, to Project Release	(See Note)
Project Release to Completion @ 15%	4,204,000
INTEREST ON BORROWED CAPITAL	
During Construction	(See Note)
During Reservoir Filling	(See Note)
CLIENT COSTS	(See Note)
TOTAL PROJECT COST (less exclusions as noted)	$32,229,000

Note: Cost to be provided by Montana Water Resources Board.